FORAMINIFERAL BIOSTRATIGRAPHY OF SITE #998 ON THE CAYMAN RISE, CARIBBEAN SEA

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Abstract

The GSSP (Global Stratotype and Section Point) for the Lutetian is located at Gorrondaxte Beach, northern Spain. Ocean Drilling Program (ODP) Leg 165 Site #998, located on the Cayman Rise, consists of pelagic limestones mixed with volcaniclastic sedimentary rocks and turbidity flows of volcanic ash that were deposited during the early to middle Eocene transition (EMET) based on previously published magnetostratigraphy and calcareous nannofossils as well as preliminary work done on planktonic foraminifera. The focus of the study was to use ODP Site 998's early to middle Eocene planktonic foraminifera to obtain a more precise correlation with the Lutetian GSSP. Cores 28R through 37R (798.9-904.8 mbsf) were classified as Unit IV of four units. They were sampled at ~ 30 cm and then made into thin sections.

Morozovella aragonensis, Morozovella subbotinae, Acarinina cuneicamerata, Turborotalia frontosa, Guembelitrioides nuttalli, and *Globigerinatheka kugleri* are all important bioevent marks and were identified in Site 998. We extended the range of *Astrorotalia palmerae* from its known biozone range, E7, into the lower portion of E9, which can be correlated with magnetostratigraphic Chron C20r/C21n. Magnetostratigraphy from previously published data has been recorrelated to the updated magnetostratigraphy from the data collected in this study. A tentative boundary, based on the last occurrence (LO) of *Turborotalia frontosa*, was placed between E7a and E7b and is noted by a red dashed line.

The magnetostratigraphy from the lowest most portion of the cores from this study interval has been confirmed with the data collected. From C22n, the chron correlation has change to better represent the planktonic foraminifera biostratigraphy. Lutetian GSSP can be compared to Site 998 using Chron C21r. The data collected is consistent with other previous microfossil

data from Site 998. The El Cobre Group, Sierra Mastra, Cuba does appear to correlate to ODP Site 998. Although much more work needs to be done in this area.

By correlating the lower sections of the ODP site 998 with the Lutetian GSSP we have better understanding of where the early to middle Eocene transition took place in the Caribbeans. A more detailed planktonic foraminiferal biostratigraphy will facilitate correlation studies with other early to middle Eocene age sections in the Caribbean such as the Calle G section in Cuba and the Rio Sambre section in Jamaica as well as the potential to work more on Site 998.

1. Introduction

The Caribbean Sea is a complex oceanic basin and is bounded (east to west) by the Yucatan Platform, the Gulf of Mexico, and the Florida-Bahamas Platforms (Chezem, 2012) and is located on top of two tectonic plates, the North American Plate and Caribbean Plate (Figure 1). The Cayman Rise, within the central Caribbean, is bordered by the Yucatan basin to the north, the Cayman Ridge and Cayman Trough to the south, and is located in the Southeast portion of the North American Plate. The Cayman Rise is dominated by a broad topographic rise across the southern part of the Yucatan Basin (Rosencrantz, 1990) (Figure 1). The Cayman Rise lies at a depths of greater than 2.6-2.8 km and has seamounts that rise to less than 2 km (Rosencrantz, 1990). To the west the Cayman Rise is dominated by an irregular plateau and has a depth of around 3.5 km (Rosencrantz, 1990). The basement south of the rise is cut by a series of ENE-WSW trending horsts and grabens. The Cayman Rise is separated from the west and north by a series of northwest facing slopes and escarpments, which define a topographic lineament extending from the western end of the Cayman Ridge to central Cuba (Rosencrantz, 1990).

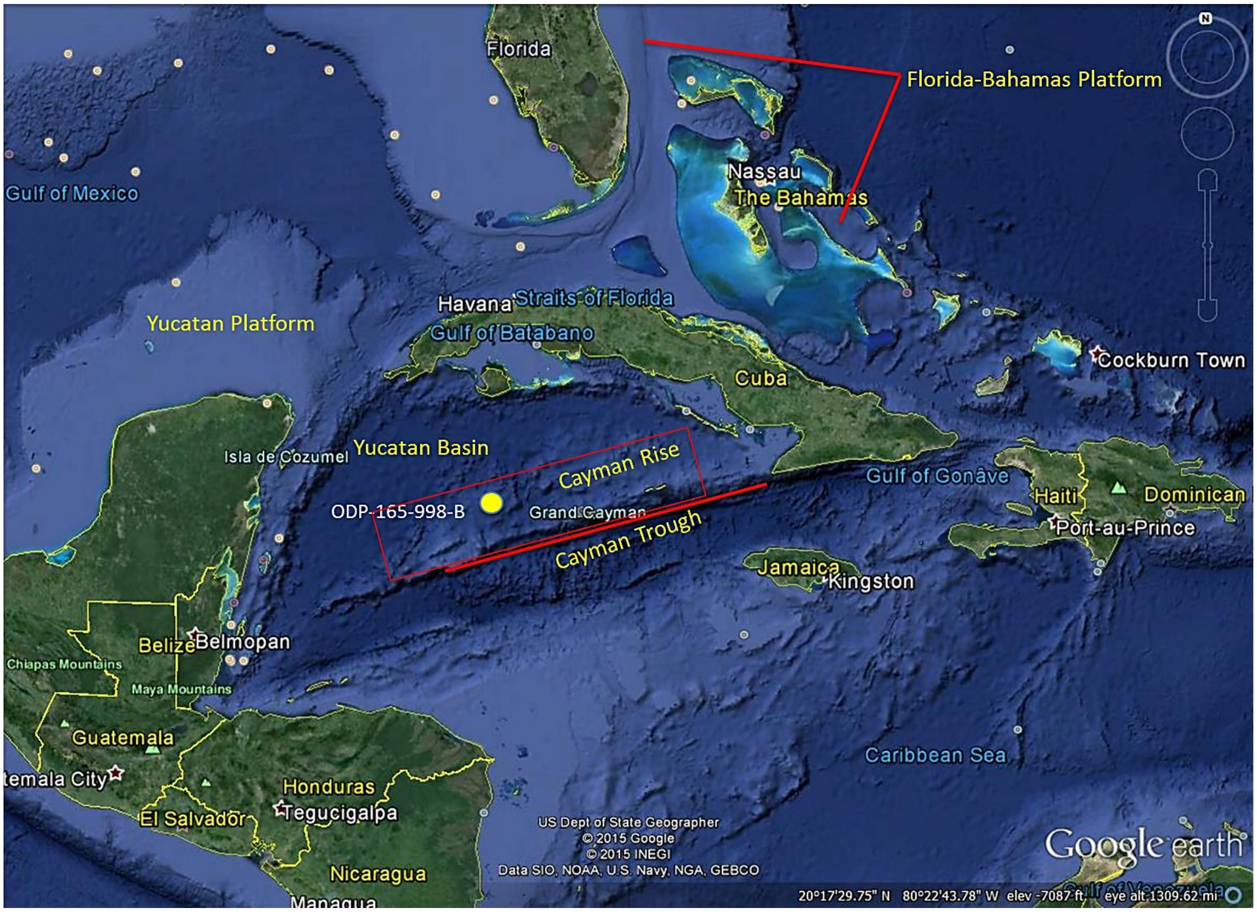

Figure 1. ODP-165-Site-998b, 19°28'52.64" N and 82°56'46.72"W. Google Earth. Image taken on December 15, 2013. Accessed on November 11, 2015.

Objectives

Precise chronostratigraphic framework from the early middle Eocene rocks of the Caribbean region is relatively unknown. This thesis will develop a high-resolution biostratigraphic framework for Ocean Drilling Program (OPD) Site 998 on the Cayman Rise. Biostratigraphic and magnetostratigraphic data will prove a chronostratigraphic timeframe for the Early Middle Eocene Transition (EMET) (50-48 Ma) in the Western Caribbean. By having a more precise correlation to the lower sections of the ODP site 998 with the Lutetian GSSP, we will have a better understanding of the early to middle Eocene transition in the Caribbean region.

The importance of this thesis project is to provide a biostratigraphic framework for future geologists to use throughout the Caribbean region both on shore and in deep-sea cores for the EMET.

Geological Setting

There are two proposed models for the Middle-Late Cretaceous origin of the Caribbean plate. The first model, the pacific origin model, requires a temporary halt of the Farallon subduction so that the Caribbean plate, which originated within the Farallon plate, is able to end up in an overriding plate position relative to the Farallon plate (Van Benthem et al., 2013). The second model, the intra-Americas model, the Caribbean plate originated from between North and South America. In Figure 2, both of the models show the tectonic evolution from the Late Cretaceous into the Paleocene and place the Caribbean plate between North and South America, which is bounded by the east dipping Farallon subduction zone to the west and the WSW dipping Great Arc of the Caribbean subduction zone located in the Caribbean Sea (Van Benthem et al., 2013). In the Northeastern section of the Caribbean plate, the Atlantic lithosphere was subducting at the Great arc of the Caribbean from the late Cretaceous until the Eocene. During the Eocene, Cuba collided with the Bahamas Carbonate Platform, which stopped the Great Arc of the Caribbean subduction zone (Figure 2f) (Van Benthem et al., 2013). After this collision, the Cuban arc moved from its initial collision with western Cuba to central Cuba (Figure 3c). The southern edge of the Lesser Antilles arc travelled eastward, resulting in a diachronous oblique collision (Van Benthem et al., 2013).

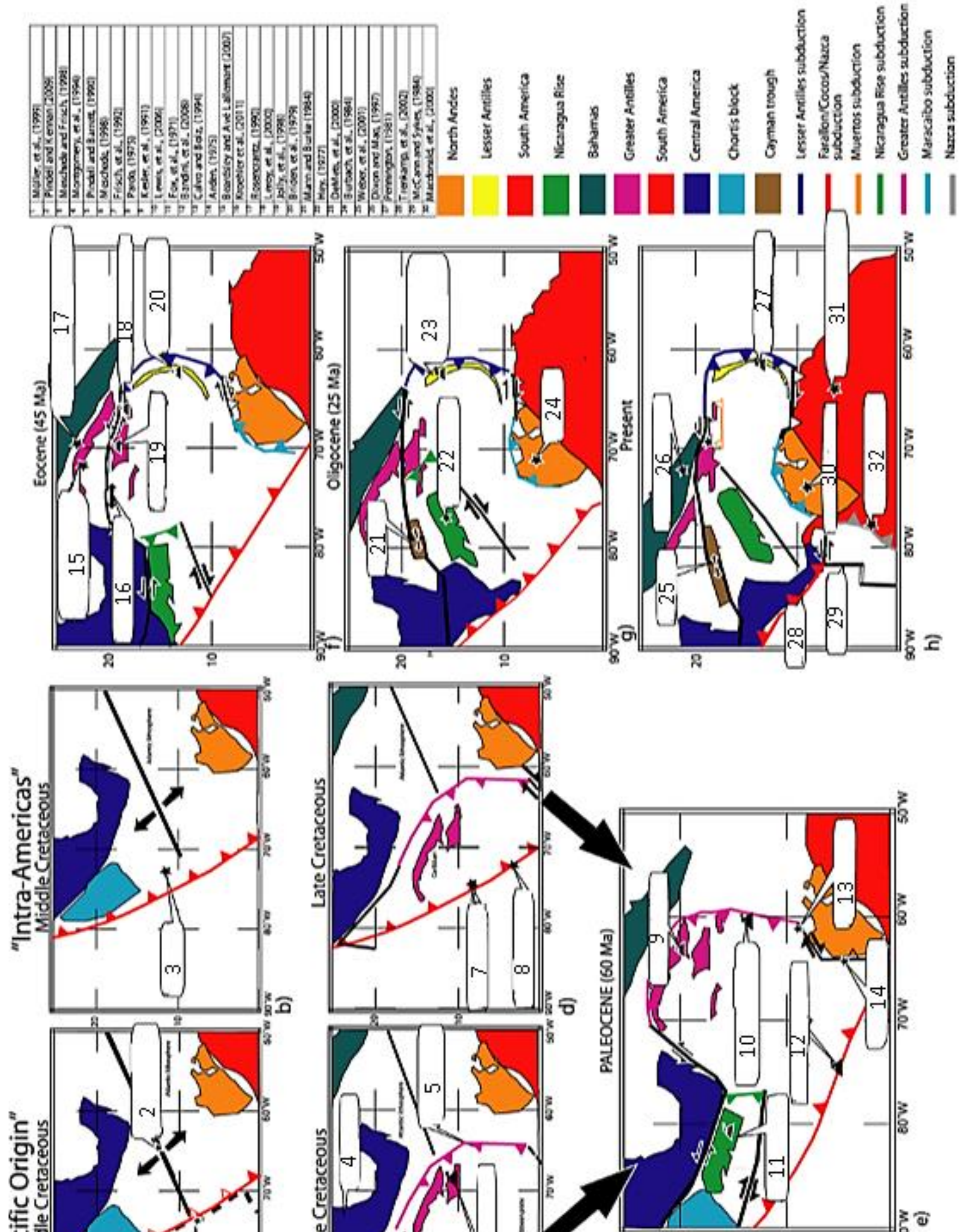
"Pacific Origin"
Middle Cretaceous
"Intra-Americas"
Middle Cretaceous
Late Cretaceous
Late Cretaceous
PALEOCENE (60 Ma)
Eocene (45 Ma)
Oligocene (25 Ma)
Present
a)
b)
c)
d)
e)
f)
g)
h)
North Andes
Lesser Antilles
South America
Nicaragua Rise
Bahamas
Greater Antilles
South America
Central America
Chortis block
Cayman trough
Lesser Antilles subduction
Farallon/Cocos/Nazca subduction
Muertos subduction
Nicaragua Rise subduction
Greater Antilles subduction
Maracaibo subduction
Nazca subduction

Figure 2. Schematic tectonic evolution of the Caribbean Plate. Solid and dashed lines represent plate boundaries that are inferred from literature. (a) The Pacific origin and (b) the "intra-Americas scenario" in the Early top Middle Cretaceous. (c-h) Paleocene-present tectonic reconstruction. The text balloons cite the relevant geological data and interpretation. (1) Temporary stop of Farallon subduction[2]. (2) Jurassic divergence between NAM and SAM created enough space for CAR to enter[1]. (3) Continuous Farallon subduction[3]. (4) Left-lateral transpression between NAM and SAM[1]. (5) Radiolarites on PR reveal Jurassic age for CAR plate[4]. (6) Magmatism at Greater Antilles occurred before magmatism in Central America[5]. (7) Caribbean Large Igneous Province was not formed as Galapagos[6]. (8) Ophiolites in Costa Rica share paleolatitudinal path with SAM[7]. (9) Extensive magmatism[8,9] and Ophiolites[10] on Greater Antilles. (10) Granites, dolerites, and basalts dredged from Aves ridge: 70-75 Ma[11]. (11) Paleocene granodiorites from well drilling at Nicaragua Rise[14]. (12) First indication of magmatism in Central American arc: Late Creatceous[12,13]. (13) 90CW rotation indicates shearing of Leeward Antilles[15]. (14) Collision of South America with GAC causes backthrusting[16]. (15) Activation of la Trocha fault and its continuation in Yucatan basin indicate shearing of Cuba[17]. (16) Start of Cayman trough as 45 Ma documents relative EW motion[18]. (17) Paleocene/Eocene: end of magmatism; Large folding underthrusting of Bahamas indicate collsion[5,8]. (18) Magmatism continues at PR until Eocene[19]. (19) Ages of magmatic rocks in Hispaniola range from 120-50 Ma[9]. (20) 40 Ma: Start of island arc magmatism at Limestone Caribbees[20]. (21) Continued opening Cayman trough[18]. (22) <Eocene limestones and conglomerates: end of subduction[14]. (23) 20 Ma: End of magmatism at limestone Caribbees[20]. 10 Ma: Start of magmatism at Lesser Antilles [20]. (24) Northward squeezing of Maracaibo block[30]. (25) Continued Cayman trough opening[18]. (26) Oblique EW RPM between NAM and CAR of ~19mm/yr[23]. (27) Segmented island arc magmatism; segmented west dipping WBZ[30,31]. (28) WBZ along coast until W. Panama[24]. (29) Activation Panama Fz at 9.5 Ma[29]. (30) South dipping WBZ under Colombia[27]. (31) Few mm convergence between NAM and SAM from GPS[26]; RPM SAM and CAR: 2 cm.yr, EW[25]. (32) GPS and WBZ indicate NAza subduction under SAM[27,28]. Taken from Van Benthem et. al., (2013) Figure 2.

The formation of the Trocha fault accommodated the northeastward plate motion and the deformation front occurred to the south along the Cauto depression in southern Cuba (Leroy et al., 2000). During the Ypresian, the Cayman basin opened (Figure 3d). After the opening of the Cayman Trough, during the Eocene, the Yucatán Basin, the Cayman Ridge, and the Cuban terranes of the Caribbean Arc were left behind as part of North America and were not subjected to further tectonic activity (Stanek et al., 2009). Shipboard Scientific Party (1997a) proposed that the subduction zone in the Cayman trough to the south of the Cayman ridge appears to be incompatible with the opening of the Yucatan basin as a pull-apart basin in the Paleocene.

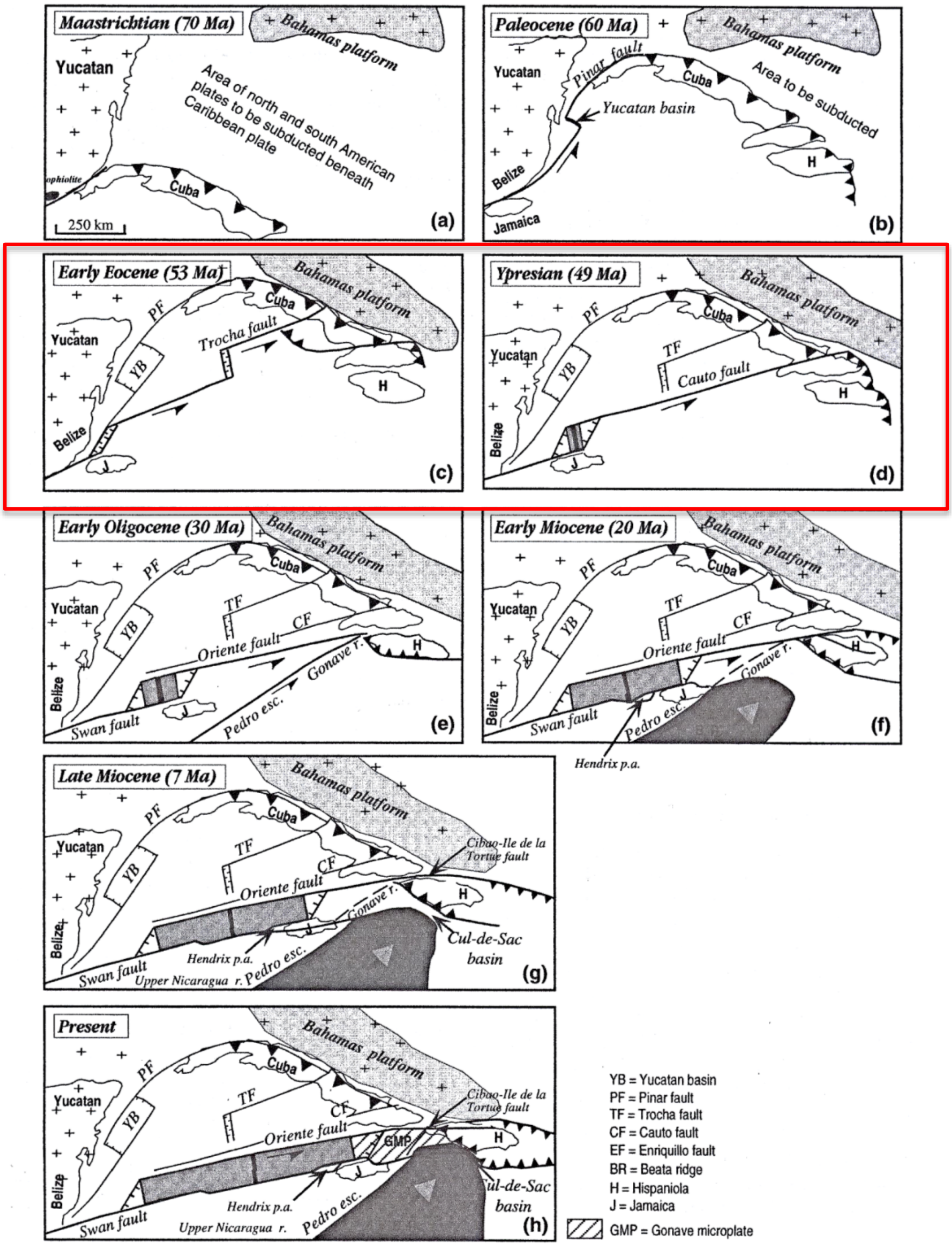

Figure 3. Tectonic reconstruction of the northern boundary of the Caribbean Plate. The red box highlights the time interval that this study focuses on. (Figure 11, An alternative interpretation of the Cayman trough evolution from a re-identification of magnetic anomalies, S. Leroy et al., *Geophys. J. Int.*, vol. 141)

Site 998

Site 998 was one of the five sites drilled during Leg 165 (Shipboard Scientific Party, 1997a). Site 998 was drilled on the Cayman Rise (Figures 1 and 4). There were two main objectives of Leg 165: 1) have a better understanding of the geological history of the Caribbean Sea and 2) to have a better framework for the Cretaceous/ Tertiary boundary (K/T boundary). Site 998 had six objectives: 1) impact-related depositional processes at the K/T boundary; 2) Late Cretaceous and Paleogene tropical ocean and climate history with particular emphasis on times of moderate to extreme global warmth and rapid change within the ocean-climate system; 3) timing of late Eocene impact events and the distribution and characterization of microtektites; 4) regional paleoceanographic conditions before and after the partial foundering of the extensive carbonate megabank across the northern Nicaraguan Rise (NNR) during the Oligocene-Miocene time; 5) Neogene history of intermediate waters in the Yucatan Basin; and lastly 6) age and nature of Cayman Rise basement rocks (Shipboard Scientific Party, 1997a). Within Site 998, the first of the six objectives was not reached due to a failure to re-enter the hole (Shipboard Scientific Party, 1997c). Leg 165 discovered Eocene and Miocene explosive volcanism and an abundance of turbidites (Shipboard Scientific Party, 1997a). The lower-middle Eocene volcaniclastic turbidites found in Site #998 suggests a more proximal source, such as the Cayman Ridge. The Miocene ashes are rhyolitic fallout layers derived from distant silicic volcanoes in Central America. The Eocene volcaniclastic turbidites and ash falls were derived from a closer island arc source (Shipboard Scientific Party, 1997a). The frequency of turbidites at Site 988 may be linked closely with the spreading activity in the Cayman Trough and the strike-slip motion along the fault zone between the North American and Caribbean Plates.

Shipboard Scientific Party (1997a/c) suggested that the Yucatan basin might have opened as a backarc basin behind the Cayman volcanic arc.

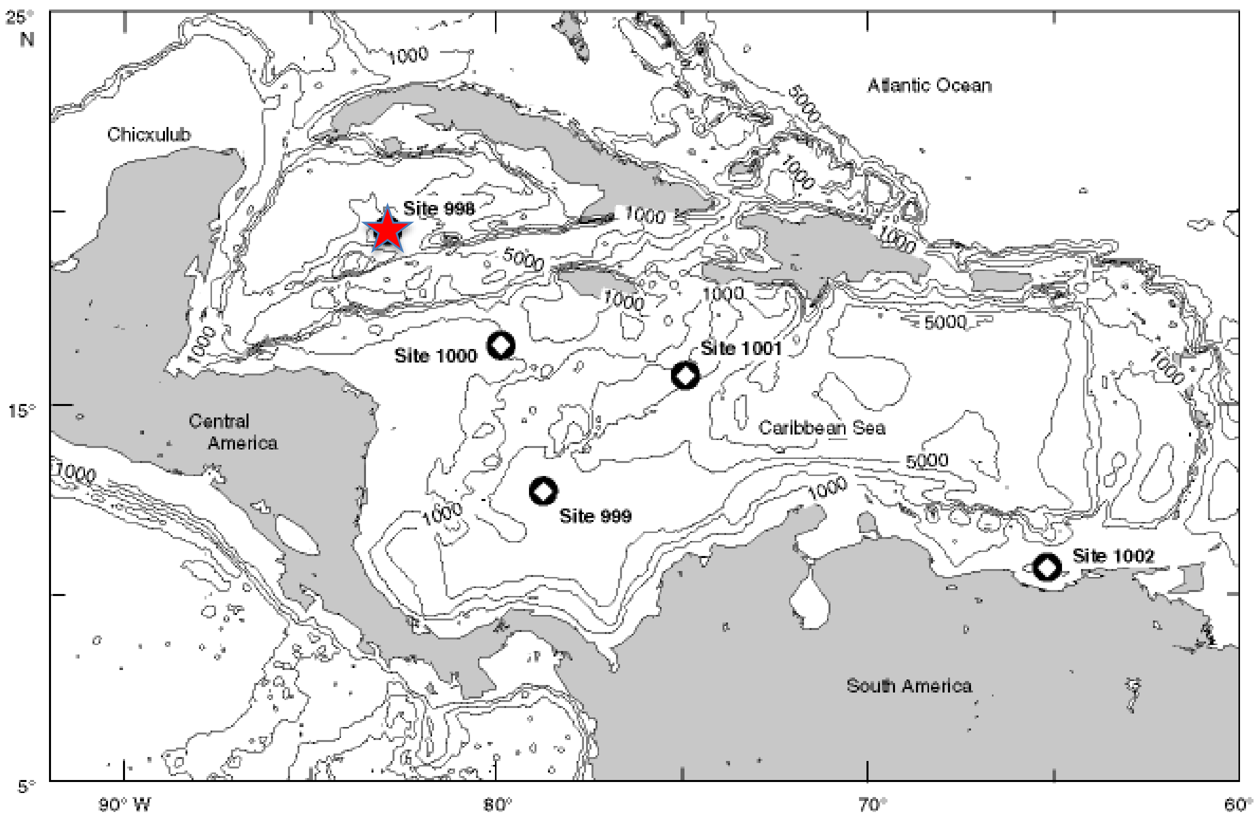

Figure 4. Bathymetric map of Leg 165. The red star is where Site 998 was drilled. Modified to highlight Site 998's location from International Ocean Drilling Program (IODP) website, http://www-odp.tamu.edu/publications/165_IR/165TOC.HTM.

There were two locations drilled, 998a and 998b. Site 998a was drilled first but was terminated in the upper Eocene nannofossil chalk. Site 998b was drilled 20 miles northeast of 998a. Site 998b is the core that will be used for this study. Site 998b was drilled down to 904.8 meters below sea floor (mbsf) and the recovery was ~ 83.1% of the drilled interval. Site 998's hole was terminated in the lower Eocene calcareous volcaniclastic sedimentary rock (Shipboard

Scientific Party, 1997a/c). Depth to basement rock was ~ 1100 – 1130 mbsf, so around 210 m of the sedimentary section to the estimated depth of the Cayman basement rock was not reached.

Stratigraphy

Four lithologic units are recognized at Site 998 (Shipboard Scientific Party, 1997a/c). Unit I (Pleistocene- lower Pliocene) consists of nannofossil ooze with foraminifera and clays interbedded with graded foraminifera ooze and ash layers. Unit II (Pliocene-upper most middle Miocene) has three subunits all of which have interbedded turbidites and ash layers. The first subunit within Unit II is comprised of clayey nannofossil mixed sediment. The second subunit within Unit II has nannofossil ooze with foraminifera and clays. The third subunit within Unit II has clays with nannofossils. Unit III (middle Miocene- middle Eocene) consists of nannofossil chalks that grade with depth into limestone with clay. Unit IV (middle Eocene- lower Eocene) is comprised of limestone with clay and calcareous volcaniclastic turbidites with interbedded altered volcanic ash and volcaniclastic turbidites (Shipboard Scientific Party, 1997c). This study will focus on Unit IV (cores 28R- 37R).

Unit IV is 137.3 m thick and is middle to early Eocene in age. Dominant lithologies are characterized by limestone, calcareous limestone with clay, calcareous volcaniclastic mixed sedimentary rock with interbedded with foraminiferal limestone, altered volcanic ash, minor chert, and altered volcanic ash with carbonate (Shipboard Scientific Party, 1997c). There are three differences that distinguish Unit IV from Unit III. They are: 1) a sharp increase in the frequency of graded foraminifers limestone, altered volcanic ash, and altered volcanic ash with carbonate; 2) a decrease in carbonate content, and 3) a slight increase in the variability of color reflectance, which indicates either relative changes in the composition of the bulk material or estimates the abundance of certain compounds (Blum, 1997; Shipboard Scientific Party, 1997c).

Calcareous limestone and calcareous limestone with clay, light greenish gray in color, occurs as thick-bedded sequences that appear relatively homogeneous with an occasional mottling and minor to moderate bioturbation. The dominant lithology shifts to calcareous volcaniclastic mixed sedimentary rock with increasing down hole depth. This mixed sedimentary rock is also thick-bedded but is less bioturbated. The main lithologies are interbedded with numerous thin to medium bedded layers of normally graded foraminiferal limestone and altered volcanic ash with carbonate (Shipboard Scientific Party, 1997c). The foraminiferal limestone beds are graded with a sharp coarse base with a fine-grained, bioturbated top. The upper part of the Unit IV have beds that are interpreted to be turbidity current deposits, which is interpreted to be reworked by bottom currents (Shipboard Scientific Party, 1997c).

There is an increase in the abundance of altered volcanic ash with carbonate noted in Core 165 998B 30R (depth of 827.8 mbsf). This increase in the abundance of ash occurs as greenish gray to dark greenish gray and thin to medium-bedded layers with sharp bases and bioturbated tops (Shipboard Scientific Party, 1997c). Several of the cores that have Unit IV contain bioturbated intervals 1 to 10 cm thick, which are a darker green than the dominant lithology and have been described by the Shipboard Scientific Party (1997c) as “wispy” laminations because of the “undulatory and disseminated nature.” The bioturbated interval colors are similar to the colors of the discrete altered volcanic ash layers and their mutual association with volcanic ash within the background sediment (Shipboard Scientific Party, 1997c). See Appendix A for the shipboard core descriptions.

Magnetostratigraphy

It is worth noting that the Shipboard Scientific Party (1997c) mentioned two problems that were encountered in obtaining a reliable magnetostratigraphy from Site #998. The first noted problem involved the removal of "a large vertical overprint that is imparted to the cores by the demagnetization" in the magnetic fields that were present during the drilling process. Most of the vertical overprint was removed by alternating-field demagnetization. The inability to completely remove the large vertical overprint from the certain samples posed a major problem because of the ample amounts of coarse-grained ash deposits and turbidite layers. This might play a small role in the reading and interpreting of the magnetic data. The second noted problem involved the presence of a substantial magnetic field in the sensor region of the shipboard cryogenic magnetometer. A substantial magnetic field in the sensor region of the shipboard cryogenic magnetometer would cause an induced magnetization in a sample that superimposed on the sample's natural remnant magnetization (Shipboard Scientific Party, 1997c). Shipboard Scientific Party (1997c) later goes on to say that the magnetostratigraphic interpretation was constrained by nannofossil biostratigraphy and that the correlations are tentative and highly dependent upon the biostratigraphy.

Biostratigraphy

Nannofossils

Okada and Burky's (1980) nannofossil biozone classifications were used in the interpretation of the nannofossil data collected from Leg 165 Site 998. Most of the Paleogene zone and subzones of Okada and Burky's (1980) were defined with some of the zones being placed tentatively (Shipboard Scientific Party, 1997b/c). The nannofossils were characterized by dissolution and overgrowth. The nannofossils also show more deterioration in the preservation of the species. There were some Eocene nannofossil events that could not be determined due to a lack of sufficient data such as the lowest occurrence of *Blackites inflatus* and the first occurrence of *Cribrocentrum reticulatum* (Shipboard Scientific Party, 1997c). Shipboard Scientific Party (1997c) also noted that the scarcity of *Chiasmolithus solitus, Nannotetrina fulgens,* and *Tribrachiatus orthostylus* near the end of their ranges lessened the reliability of the events. This could mean that particular key marker species are rare or not observed. These missing events were usually correlated to the lower middle Eocene and the upper early Eocene. Because of these missing events a tentative biozone CP11/CP10 (coccolith Paleogene) boundary (E7/E6 boundary) was placed between cores 33R and 34R (Shipboard Scientific Party, 1997c). Nannofossils, those that were identified as important by the Shipboard Scientific Party (1997), were lowest occurrence (LO) of *Chiasmolithus gigas,* LO of *Nannotetrina fulgens,* LO of *Discoaster sublodoesis,* first occurrence (FO) of *Tribrachiatus orthostylus,* and LO of *Discoaster lodeonsis* (Sigurdsson et al., 1997).

Radiolarian

Biozones used for the radiolarian biostratigraphy utilized the definitions of Nigrini and Sanfilippo (1998). The zonations range from RP12 (Radiolarian Paleogene) to RP 8 (Nigrini and Sanfilippo, 2000). Just like with the nannofossils and the planktonic foraminifera, the radiolarians showed a low diversity throughout the middle Eocene due to poor preservation of the species (Nigrini and Sanfilippo, 2000). Nigrini and Sanfilippo (2000) noted that the zonation of radiolarians was based off of the calcareous nannofossil biostratigraphy.

Planktonic Foraminifera

It was noted in Shipboard Scientific Party (1997) that the first occurrence (FO) of *Globigerapsis kugleri* places the base of biozone E9 (formally zone P11) between samples 165-998B-27R-CC and 28R-CC (core capture). Based on the presence of *Morozovella aragonensis* and *Acarinina pentacamerata* in 165-998B-37R-CC it is suggested that the oldest sediments cored at site 998b are no younger than biozone E8 (formally zone P8) (Shipboard Scientific Party, 1997c). Shipboard Scientific Party (1997c) also observed that the preservation of foraminifera were almost uniformly poor due to increased lithification.

2. Methods

This project used an Olympus CH40R4100, petrographic microscope to identify foraminifera to species level, as well as for a foraminifera count. The planktonic foraminifera were photographed using a Canon EOS Rebel T1i 500D camera equipped with a Martin Microscope-SLR 2.5x Universal DSLR to Microscope T-mount Adapter, mounted on top of the petrographic thin section microscope (Figure 7). Identifying the foraminiferal taxonomy and the placement of biozones utilized both the *Atlas of Eocene Planktonic Foraminifera*: *Cushman Foundation Special Publication, no. 41* and the reclassification of the biozones from Wade et al. (2011) (Figures 8). Only the planktonic foraminifera were counted, identified, and photographed because the benthic foraminifera were poorly preserved. Planktonic foraminifera will be identified mainly by their test shape. Wall structure and texture, aperture, and umbilicus will also be used in identification depending on how well they are preserved in thin section. See Appendix D for descriptions of planktonic foraminifera. The preservation state classification (moderate, poor, and very poor) was taken from information provided in Shipboard Scientific Party (1997c) and redefined to fit the observed foraminifera. Preservation states are defined by the crystallization of the test chambers, test shape, and wall structure and texture. Microsoft Excel was used for recording counts and cataloging recognizable planktonic foraminifera. The samples were collected in 30 cm intervals in the available core. The thin sections were made by National Petrographics to support one of Dr. Fluegeman's research efforts in the Caribbean in 1998. All stratigraphic zones are within the guidelines set by the International Subcommission on Stratigraphic Classification on IUGS International Commission on Stratigraphic in the International Stratigraphic Guide (1994).

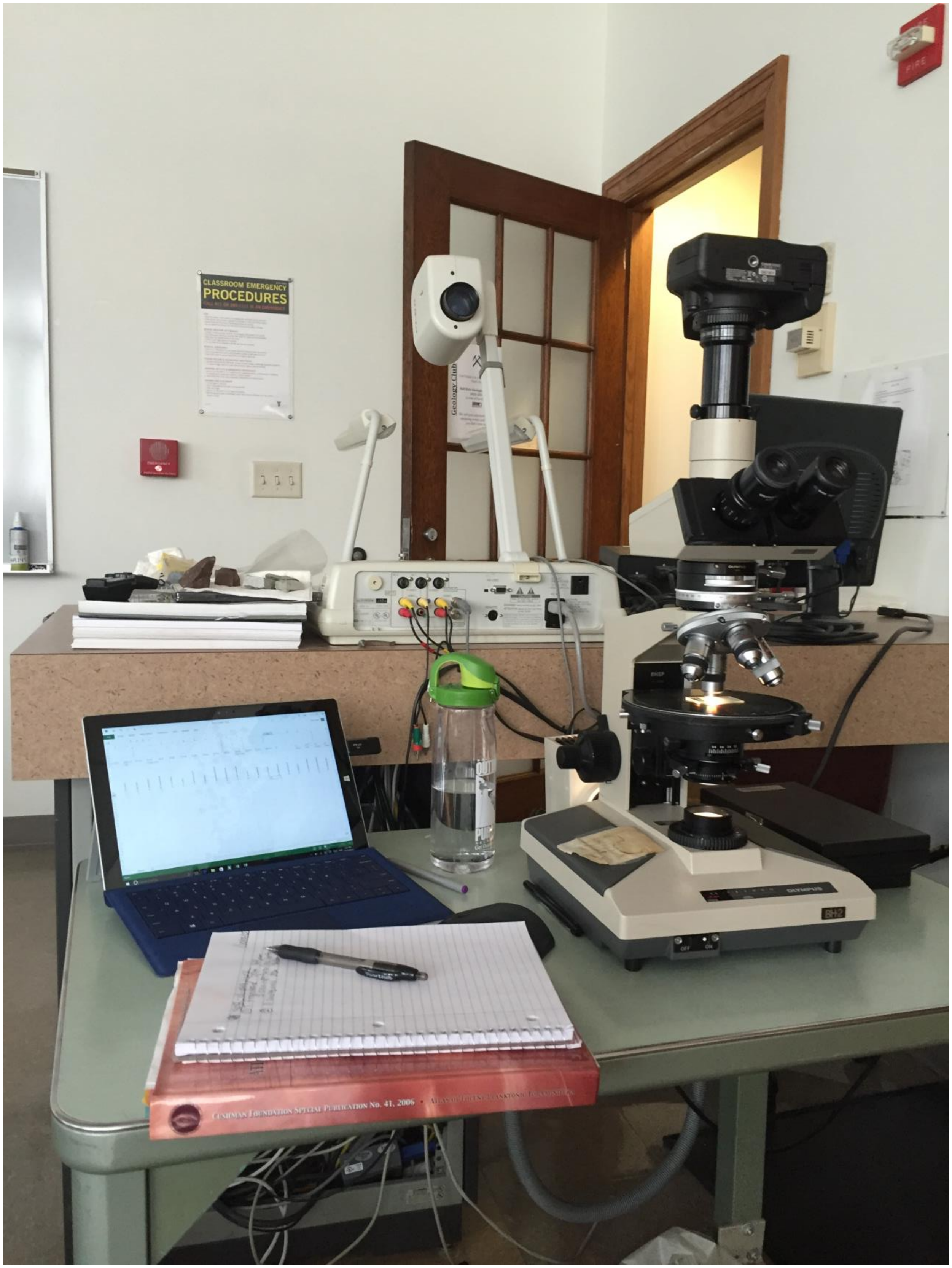

Figure 5. Photo of the petrographic thin section microscope used for this study.

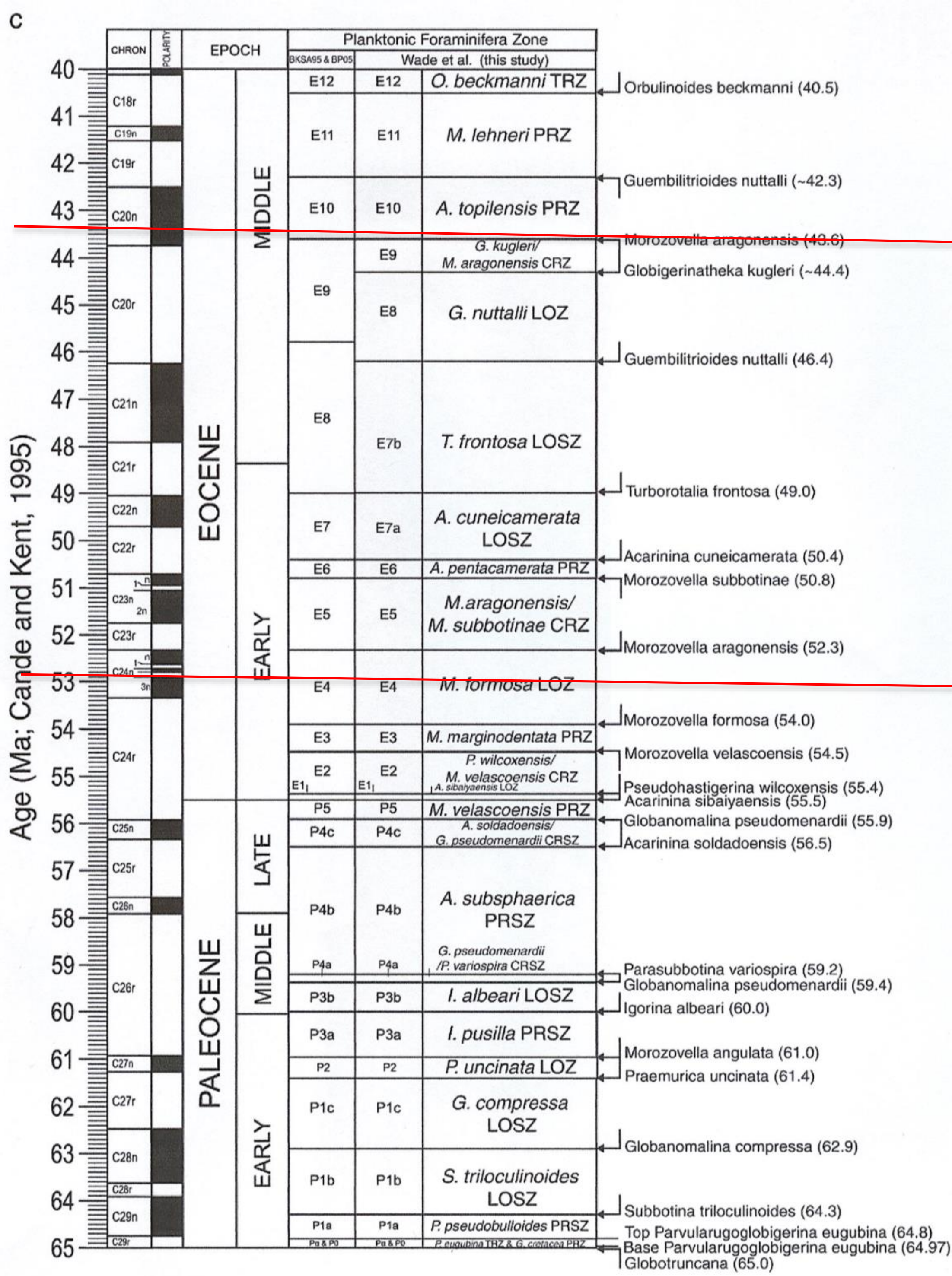

Figure 6. Planktonic foraminiferal bioevents with a focus on the early to middle Eocene. Biozones between the red lines indicate the zonations used for this study. The column to the left of Wade et al., (this study) is the previously known biozonations from Berggren and Pearson (2005) and Berggren et al.(1995). Taken from Wade et al. (2011).

3. Results

Planktonic Foraminifera

The foraminifera preservation states noted in the thin section analysis is shown Figure 9. There are three classes of preservation in Site #998b: very poor (Figure 10 A & B), poor (Figure 10 C & D), and moderate (Figure 10 E & F). These preservation states are defined by the recrystallization of foraminifera test, clarity of foraminifera test shape and wall texture, and how many individual foraminifera were identified. The middle to lower Eocene section of the core consists of moderate to very poor preservation states (Shipboard Scientific Party, 1997c). More information of the preservation states and other notes on the thin sections can be found in Table 1 of Appendix B.

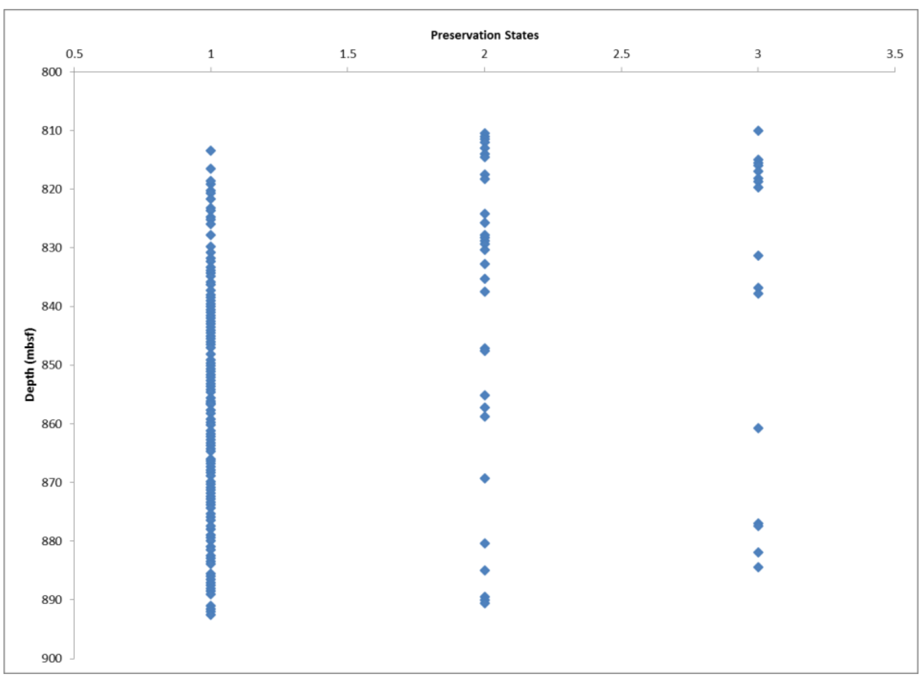

Figure 7. Preservation of planktonic foraminifera of Site #998 with 1= Very poor preservation, 2= Poor preservation, and 3= Moderate preservation.

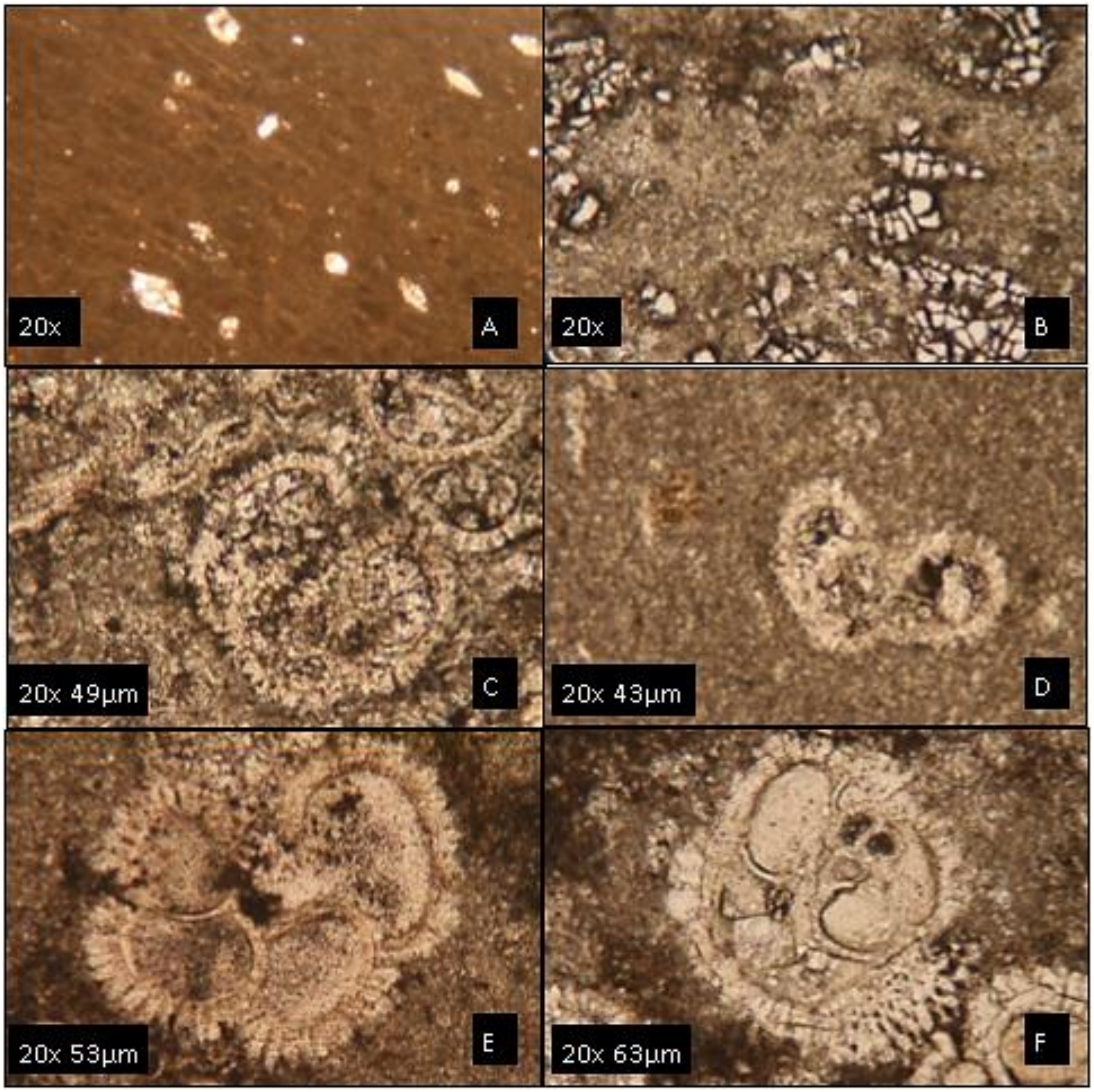

Figure 8. Preservation state of Site 998. (A-B) Very poor. (C-D) Poor. (E-F) Moderate.

The complete distribution of planktonic foraminifera from Site 998 can be found in Table 1. Abundances of planktonic foraminifera range from scarce (<5%) to copious (>5%) amounts. In core 37R (Table 1), there was an abundance of *Morozovella formosa* (43.04%) (Plate 8, A & B), *Acarinina pentacamerata* (20.25%) (Plate 2, A-C), *Morozovella subbotinae* (12.66%) (Plate 8, C & D), *Morozovella aragonensis* (11.39%) (Plate 7, A & B), and *Acarinina querta* (5.063%) (Plate 4, D-F). *Acarinina bullbrooki* (6.329%) (Plate 1, A-C) and *Acarinina primativa* (1.266%) were the other two species identified. The appearance of *Morozovella* (53 foraminifera counted) exceeds the appearance of *Acarinina* (25 foraminifera counted) in this core. Most of 37R's preservation was very poor to poor. There were few thin sections that had moderate preservation.

In core 36R (Table 1), there was an abundance of *Morozovella subbotinae* (11.25%), *Morozovella aragonensis* (11.25%), and *Morozovella formosa* (10%). *Morozovella crater* (2.5%) (Plate 7, E & F), *Acarinina pentacamerata* (0.513%), *Acarinia quetra* (0.1%), *Acarinina cuneicamerata* (0.013%) (Plate 2, D-F), *Acarinina bullbrooki* (0.013%) and *Acarinina primitiva* (0.013%) (Plate 4, A-C) were the other species identified that were not abundant. Core 36R ranged from poor to very poor preservation and most of 316R had little to no identifiable foraminifera species. Species that were present in core 36R had been recrystallized.

In core 35R (Table 1), there was an abundance of *Acarinina pentacamerata* (52.86%), *Morozovella aragonensis* (12.86%), *Acarinina quetra* (8.571%), *Acarinina primitiva* (8.571%), and *Acarinina praetopilensis* (8.571%) (Plate 3, D-F). *Acarinina bullbrooki* (1.429%), *Acarinina pseudotopilensis* (1.429%), *Acarinina cuneicamerata* (1.429%), *Acarinina coalengensis* (1.429%) (Plate 1, D-F), *Morozovella crater* (1.429%), and *Globoturborotalita bassrivernesis* (1.429%) (Plate 6, A & B) were the species noted to be least abundant. In this core there is a shift in the abundances of genera, from a dominant abundance of *Morozovellas* (tropical waters) to a dominant abundance of *Acarininas* (subtropical/temperate waters). There were more fluctuations in the preservation states. Very poor preservation dominates 35R with little to no identifiable foraminifera species. The species that were present had been recrystallized which made identification difficult.

In core 34R (Table 1), *Acarinina pentacamerata* (37.04%), *Acarinina primitiva* (18.52%), *Morozovella aragonensis* (11.11%), *Acarinina bullbrooki* (11.11%), and *Acarinina praetopilensis* (7.407%) *Morozovella caucasica* (7.407%) (Plate 7, C & D) were the abundant species identified. *Subbotina eocenea* (3.704%) and *Morozovella formosa* (3.704%) were the species that was noted to be not as abundant. Most of 34R had little to no identifiable foraminifera species and the species that were present had been recrystallized. The foraminifera that were identified in core 34R had enough preservation of test shape and in some cases wall texture to make an identification.

In core 33R (Table 1), there was an abundance of *Acarinina pentacamerata* (22.22%), *Acarinina praetopilensis* (16.67%), *Subbotina eocenea* (13.89%) (Plate 10, A-C), *Acarinina bullbrooki* (11.11%), *Acarinina collactea* (11.11%), *Turborotalia frontosa* (5.556%) (Plate 10, D-F), and *Subbotina corpulenta* (5.556%) (Plate 9, E & F). There were five foraminifera species that were not abundant. Those species are: *Acarinina primativa* (2.778%),), *Subbotina crocicapetrura* (2.778%) (Plate 9, C & D), *Morozovella aragonensis* (2.778%) *Morovella caucasica* (2.778%), and *Igorina broedermanni* (2.778%) (Plate 6, F). Majority of 33R had little to no identifiable foraminifera and the species that were present had been recrystallized. Although, the foraminifera that were identified had enough preservation of test shape and in some cases wall texture to make an identification.

In core 32R (Table 1), *Globigerinatheka subconglobata* (22.97%) (Plate 5, E & F), *Acarinina praetopilensis* (17.57%), *Morozovella aragonensis* (12.16%), *Acarinina pentacamerata* (10.81%), *Acarinina bullbrooki* (9.459%), *Acarinina collactea* (8.108%), and *Subbotina corpulenta* (5.405%), and were the most abundant identified. *Acarinina cuneicamerata* (2.703%), *Guembelitriodies nuttalli* (2.703%) (Plate 6, C & D), *Acarinina primitive* (1.351%), *Morozovella caucasica* (1.351%), *Turborotalia frontosa* (1.351%), and *Parasubbotina inaequispira* (0.0263%) (Plate 8, E & F) were the least abundant species identified.

In core 31R (Table 1), there was an abundance of *Acarinina praetopilensis* (22.22%), *Morozovella aragonensis* (20%), *Acarinina collactea* (15.56%), *Globigerinatheka subconglobata* (13.33%), *Subbotina eocaena* (11.11%), and *Acarinina bullbrooki* (6.667%) identified. *Acarinina cumiecamerata* (4.44%), *Turborotalia frontosa* (2.22%), *Acarinina pentacamerata* (2.222%) and *Globorturborotalita bassriverensis* (2.222%) were the least abundant. This is the only core where *Acarinina pentacamerata* is noted to be the least abundant unlike the other eight cores that an abundance of *Acarinina pentacamerata*. Majority of 31R had little to no identifiable foraminifera species and the species that were present had been recrystallized. Although, the foraminifera that were identified had just enough preservation of test shape and in some cases wall texture to make a reliable identification.

In core 30R (Table 1), *Acarinina praetopilensis* (33.16%), *Acarinina pentacamerata* (20.92%), *Morozovella aragonensis* (11.73%), and *Globigerinatheka subconglobata* (10.2%) were identified to be the most abundant. While, *Acarinina collactea* (2.551%) (Plate 2, A-C), *Turborotalia frontosa* (2.041%), *Guembelitriodies nuttalli* (1.02%), *Morozovella crater* (1.02%), *Acarinina bullbrooki* (0.694%), *Acarinina coalengensis* (0.51%), *Subbotina corpulenta* (0.51%), *Subbotina crociapertra* (0.51%), and *Subbotina eoceana* (0.0612%) were the least abundant.

In core 29R (Table 1), there was an abundance *Acarinina praetopilensis* (22.92%), *Acarinina pentacamerata* (20.14%), *Subbotina eocaena* (10.42%), *Globigerinatheka subconglobata* (9.722%), *Morozovella aragonensis* (8.333%), and *Acarinina bullbrooki* (5.556%). *Turborotalia frontosa* (4.861%), *Globoturborotalita bassrivernesis* (3.472%), *Guembelitriodes nuttalli* (3.472%), *Acarinina collactea* (3.472%), *Astrorotalia palmerae* (2.083%) (Plate 5, A & B), *Morozovella caucasica* (1.389%), *Hankenina leibusi* (1.389%) (Plate 6, E), *Acarinina aspensis* (0.964%), *Acarinina coalengensis* (0.694%), *Morozovella crater* (0.694%), *Praemurica ? lozanoi* (0.694%) (Plate 9, A & B), and *Parasubbotina inaequispira* (0.0069%). Both 29R and 28R had a wide range of different planktonic foraminifera species.

Acarinina praetopilensis (16.28%), *Morozovella aragonensis* (14.95%), *Globigerinatheka mexicana* (12.29%) (Plate 5, D), *Subbotina eocaena* (11.63%), *Globigerinatheka kugleri* (9.635%) (Plate 5, C), *Globoturborotalita bassrivernesis* (6.977%), *Acarinina pentacamerata* (6.312%), and *Acarinina bullbrooki* (5.98%) were the most abundant species identified in core 28R (Table 1). The least abundant species in this core were *Guembelitriodies nuttalli* (3.987%), *Turborotalia frontosa* (1.993%), *Acarinina collactea* (1.993%), *Acarinina aspensis* (1.329%), *Astrorotalia palmerae* (1.329%), *Turborotalia possagnoensis* (0.997%), *Globigerinatheka subconglobata* (0.997%), *Pseudoglobigerinella bolivariana* (0.664%), *Subbotina corpulenta* (0.664%), *Praemurica ? lozanoi* (0.664%), *Morozvella crater* (0.664%), *Parasubbotina eoclava* (0.332%), and *Acarinina cuniecamerata* (0.332%).

There were other fossil remnants observed in thin section. Algae spores are abundant throughout the study interval. Shell fragments were found throughout the interval but they were not as abundant as algae spores. Volcanic ash layers and turbidities mixed with planktonic foraminifera and volcanic ash appear periodically throughout the interval. Notes and comments on the thin sections observations are located in Appendix B, Table 1.

Benthic Foraminifera

Shipboard Scientific Party (1997a) observed very few benthic foraminifera but noted two specimens appeared to be recrystallized ghosts of disk-shaped larger foraminifera. This is confirmed by observations made during data analysis and data compilation of this study. Benthic specimens are found in 33R-01-048-050, 33R-03-100-102, 35R-01-101-103, and multiple specimens are found in 36R-02-000-003. All of the benthic specimens found have been recrystallized so identification is problematic. At best, the benthics can be classified to the genera; *Nummulites* sp. (Plate 11, A-C), *Heterostegina* sp. (Plate 11, D), and *Discosyclia* sp. (Plate 11, E & F).

Table 1. Distribution of planktonic foraminifera counts from Site #998. The gray boxes signify that there were no foraminifera identified in the thin section. The sampling intervals are at the top of the table and the foraminifera identification is location of the right-hand side of the table. Numbers represents the amount of foraminifera identified and counted in each sampling interval.

	Acarinina										Astrorotalia	Globigerinatheka			Globoturborotalita	Guembelitriodies	Hantkenina	Igorina	Parasubbotina	Praemurica	Pseudoglobigerinella	Morozovella					Subbotina			Turborotalia		
Foraminfera ID	*aspensis (?)*	*bullbrooki*	*collactea*	*coalengensis*	*cuneicamerata*	*pentacamerata*	*praetopilensis*	*primitiva*	*pseudotopilensis*	*quetra*	*palmerae (?)*	*kugleri*	*mexicana*	*subconglobata*	*bassriverensis*	*nuttalli*	*liebusi*	*broedermanni*	*eoclava*	*lozanoi*	*bolivariana (?)*	*aragonensis*	*caucasica*	*crater*	*formosa*	*subbontinae*	*corpulenta*	*crociapertura*	*eocaena*	*frontosa*	*possagnoensis (?)*	*Total #*
28R-02-000-003		4					2							1	1	1						1		1								11
28R-02-050-053		2					7					2	1	1	1							4										18
28R-02-099-102		4					1						2							1				1								9
28R-03-000-003		2	1				3					3		1	2	1						3							1			17
28R-03-057-054			1				1					1										5							2			10
28R-04-000-003			1				2								3	1						13							3			23
28R-04-049-051																													1			1
28R-04-098-100							7						1		2							6							3	1		20
28R-05-000-002						1	8					4	9			2						2							3	4		33
28R-05-054-057		2	1									2	5		4	4													7	1	1	27
28R-05-100-103												1	9		5	1						10							4			30
28R-06-000-003		2	2			3	5				3	9	10									1							4		1	40
28R-06-054-056							1					3																				4
28R-06-100-103	2	2			1	1	1					1			2	1			1		1						1		3		1	18
28R-07-000-001	1					3	3					1									1						1		2			12
28R-CC-023-026	1					11	8				1	2			1	1				1									2			28
Total	4	18	6	0	1	19	49	0	0	0	4	29	37	3	21	12	0	0	1	2	2	45	0	2	0	0	2	0	35	6	3	301
%	1.329	5.98	1.993	0	0.332	6.312	16.28	0	0	0	1.32890365	9.635	12.29	0.997	6.976744186	3.986710963	0	0	0.332225914	0.6644518	0.664451827	14.95	0	0.664	0	0	0.664	0	11.63	1.993	0.997	100
29R-01-002-005			2			5	8				3				2														1			21
29R-01-052-055			1			2	1															2							2	2		10
29R-01-103-106						1																								1		2
29R-02-000-003	1			1		2	2								1	1													1	2		11
29R-02-049-052			1			2	3													1		2										9
29R-02-100-103		1	1			2								1	1		1					1	1	1					1	2		13
29R-03-047-052						2	2							1																		5
29R-03-103-106																						1										1
29R-04-000-003							2															3							2			7
29R-04-050-053		2				2								1			1												1			7
29R-04-100-103							3							2															1			6
29R-05-000-004		2				3	3							5		1													4			18
29R-05-049-052		2				3	3								1	1							1									11
29R-05-096-098		1				3	4							4		1						3							1			17
29R-CC-010-013						2	2									1													1			6
Total	1	8	5	1	0	29	33	0	0	0	3	0	0	14	5	5	2	0	0	1	0	12	2	1	0	0	0	0	15	7	0	144
%	0.694	5.556	3.472	0.694	0	20.14	22.92	0	0	0	2.08333333	0	0	9.722	3.472222222	3.472222222	1.3888889	0	0	0.6944444	0	8.333	1.389	0.694	0	0	0	0	10.42	4.861	0	100
30R-01-000-004							2							2		2						1										7

Table 1 (cont). Distribution of planktonic foraminifera from Site #998.

	Acarinina										Astrorotalia	Globigerinatheka			Globoturborotalita	Guembelitriodies	Hantkenina	Igorina	Parasubbotina	Praemurica	Pseudoglobigerinella	Morozovella					Subbotina			Turborotalia		
Foraminfera ID	*aspensis (?)*	*bullbrooki*	*collactea*	*coalengensis*	*cuneicamerata*	*pentacamerata*	*praetopilensis*	*primitiva*	*pseudotopilensis*	*quetra*	*palmerae (?)*	*kugleri*	*mexicana*	*subconglobata*	*bassriverensis*	*nuttalli*	*liebusi*	*broedermanni*	*eoclava*	*lozanoi*	*bolivariana (?)*	*aragonensis*	*caucasica*	*crater*	*formosa*	*subbontinae*	*corpulenta*	*crociapertura*	*eocaena*	*frontosa*	*possagnoensis (?)*	*Total #*
30R-01-049-052		3		1		7	7							2								1							1	1		23
30R-01-097-100		1				4	9							2															1			17
30R-02-000-004						1	5															2					1		1			10
30R-02-049-052		1				2	2							3								2										10
30R-02-100-104						2	4															2								1		9
30R-03-000-003																													1	1		2
30R-03-050-053		5				4	7							1								7		1								25
30R-03-100-103						4								1								1		1					2	1		10
30R-04-000-003		1				1								2								1										5
30R-04-049-052						1	2							1															1			5
30R-04-104-107							1																									1
30R-05-002-005						2	2																									4
30R-05-050-053						1	4																									5
30R-05-101-104		1	1			2	3							1								1						1				10
30R-06-000-003						1	7															4										12
30R-06-049-053						2	2																									4
30R-06-101-104																						1										1
30R-07-000-002		5	4			4	5							3															5			26
30R-07-050-052																																0
30R-CC-000-003		2				3	3							2																		10
Total	0	19	5	1	0	41	65	0	0	0	0	0	0	20	0	2	0	0	0	0	0	23	0	2	0	0	1	1	12	4	0	196
%	0	9.694	2.551	0.51	0	20.92	33.16	0	0	0	0	0	0	10.2	0	1.020408163	0	0	0	0	0	11.73	0	1.02	0	0	0.51	0.51	6.122	2.041	0	100
31R-01-000-003		1					3							3								2							2			11
31R-01-050-053						1																										1
31R-01-100-103																																0
31R-02-000-003							1																									1
31R-02-050-053																																0
31R-02-100-103																																0
31R-03-000-004																																0
31R-03-050-052																																0
31R-03-100-103			3				2																						1	1		7
31R-04-000-003														2								1										3
31R-04-050-053		1																				1							1			3
31R-04-098-101							1															2										3
31R-05-000-003			2				2															1										5
31R-05-049-052		1	1		1																	1										4

Table 1 (cont). Distribution of planktonic foraminifera from Site #998.

	Acarinina										Astrorotalia	Globigerinatheka			Globoturborotalita	Guembelitriodies	Hantkenina	Igorina	Parasubbotina	Praemurica	Pseudoglobigerinella	Morozovella					Subbotina			Turborotalia		
Foraminfera ID	aspensis (?)	bullbrooki	collactea	coalengensis	cuneicamerata	pentacamerata	praetopilensis	primitiva	pseudotopilensis	quetra	palmerae (?)	kugleri	mexicana	subconglobata	bassriverensis	nuttalli	liebusi	broedermanni	eoclava	lozanoi	bolivariana (?)	aragonensis	caucasica	crater	formosa	subbontinae	corpulenta	crociapertura	eocaena	frontosa	possagnoensis (?)	Total #
31R-05-100-102																																0
31R-06-000-002																																0
31R-06-049-051																																0
31R-06-099-101			1				1																						1			3
31R-07-000-002					1																	1										2
31R-CC-048-050														1	1																	2
Total	0	3	7	0	2	1	10	0	0	0	0	0	0	6	1	0	0	0	0	0	0	9	0	0	0	0	0	0	5	1	0	45
%	0	6.667	15.56	0	4.444	2.222	22.22	0	0	0	0	0	0	13.33	2.222222222	0	0	0	0	0	0	20	0	0	0	0	0	0	11.11	2.222	0	100
32R-01-003-005			1		2									2																1		6
32R-01-056-058		1	2				2							1								2										8
32R-01-100-102																																0
32R-02-000-002			2				1							3		1						1(?)										7
32R-02-047-049			1				2							2																		5
32R-02-102-105																																0
32R-03-005-007		1																				1										2
32R-03-048-051																						2										2
32R-03-100-102							1																									1
32R-04-002-004																																0
32R-04-050-052																																0
32R-04-099-101							1							3		1																5
32R-05-000-002																																0
32R-05-049-051		1					1							2								1										5
32R-05-100-102		1				1																1	1									4
32R-06-000-003						1																					1					2
32R-06-050-052		1				3	1							3								2(?)					2		1			11
32R-06-101-103		2				1(?)	2	1						1																		6
32R-07-000-002						2	2															2							1			7
32R-CC-014-016						1																2(?)					1		1			3
Total	0	7	6	0	2	8	13	1	0	0	0	0	0	17	0	2	0	0	0	0	0	9	1	0	0	0	4	0	3	1	0	74
%	0	9.459	8.108	0	2.703	10.81	17.57	1.351	0	0	0	0	0	22.97	0	2.702702703	0	0	0	0	0	12.16	1.351	0	0	0	5.405	0	4.054	1.351	0	100
33R-01-000-002																																0
33R-01-048-050		1	1				1															1	1					1				6
33R-01-098-100																																0
33R-02-005-007																																0
33R-02-049-051		1				2(?)																							2	1		4
33R-02-099-105			1																										1			2

Table 1 (cont). Distribution of planktonic foraminifera from Site #998.

	Acarinina										Astrorotalia	Globigerinatheka			Globoturborotalita	Guembelitriodies	Hantkenina	Igorina	Parasubbotina	Praemurica	Pseudoglobigerinella	Morozovella					Subbotina			Turborotalia		
Foraminfera ID	*aspensis (?)*	*bullbrooki*	*collactea*	*coalengensis*	*cuneicamerata*	*pentacamerata*	*praetopilensis*	*primitiva*	*pseudotopilensis*	*quetra*	*palmerae (?)*	*kugleri*	*mexicana*	*subconglobata*	*bassriverensis*	*nuttalli*	*liebusi*	*broedermanni*	*eoclava*	*lozanoi*	*bolivariana (?)*	*aragonensis*	*caucasica*	*crater*	*formosa*	*subbontinae*	*corpulenta*	*crociapertura*	*eocaena*	*frontosa*	*possagnoensis (?)*	*Total #*
33R-03-000-003			1																		1(?)						1					2
33R-03-052-054																																0
33R-03-100-102		1	1			6	5	1										1									1		2	1		19
33R-04-000-002																																0
33R-04-050-052						1(?)																										0
33R-04-096-099																																0
33R-05-000-003						1(?)																										0
33R-05-050-053						1																										1
33R-05-101-103																																0
33R-06-000-002		1				1																								1(?)		2
33R-06-050-053																																0
33R-CC-004-006								1(?)																								0
total	0	4	4	0	0	8	6	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	2	1	5	2	0	36
%	0	11.11	11.11	0	0	22.22	16.67	2.778	0	0	0	0	0	0	0	0	0	2.778	0	0	0	2.778	2.778	0	0	0	5.556	2.778	13.89	5.556	0	100
34R-01-000-003								4																								4
34R-01-050-052																																0
34R-01-098-100																																0
34R-02-000-002																																0
34R-02-050-053																																0
34R-02-100-102																																0
34R-03-000-002						3	1	1															1						1			7
34R-03-050-053																								1(?)								0
34R-03-100-102		1				3																	1									5
34R-04-000-002		2				1	1																									4
34R-04-050-052																																0
34R-04-100-102						1															2(?)											1
34R-05-003-005																																0
34R-05-048-050																																0
34R-05-100-104																						3										3
34R-06-000-004						2																										2
34R-06-051-054																									1							1
34R-CC-012-014																																0
Total	0	3	0	0	0	10	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	1	0	0	0	1	0	0	27
%	0	11.11	0	0	0	37.04	7.407	18.52	0	0	0	0	0	0	0	0	0	0	0	0	0	11.11	7.407	0	3.704	0	0	0	3.704	0	0	100
35R-01-000-003																																0
35R-01-050-052																																0
35R-01-101-103		1				4	1			1					1																	8

Table 1 (cont). Distribution of planktonic foraminifera from Site #998.

	Acarinina										Astrorotalia	Globigerinatheka			Globoturborotalita	Guembelitriodies	Hantkenina	Igorina	Parasubbotina	Praemurica	Pseudoglobigerinella	Morozovella					Subbotina			Turborotalia		
Foraminfera ID	*aspensis (?)*	*bullbrooki*	*collactea*	*coalengensis*	*cuneicamerata*	*pentacamerata*	*praetopilensis*	*primitiva*	*pseudotopilensis*	*quetra*	*palmerae (?)*	*kugleri*	*mexicana*	*subconglobata*	*bassriverensis*	*nuttalli*	*liebusi*	*broedermanni*	*eoclava*	*lozanoi*	*bolivariana (?)*	*aragonensis*	*caucasica*	*crater*	*formosa*	*subbontinae*	*corpulenta*	*crociapertura*	*eocaena*	*frontosa*	*possagnoensis (?)*	*Total #*
35R-02-000-003						2	1	1														7		1								12
35R-02-050-053																																0
35R-02-105-108																																0
35R-03-000-002																																0
35R-03-048-051																																0
35R-03-100-103						1			1																							2
35R-04-000-002						3		1		2																						6
35R-04-049-052																																0
35R-04-100-102																																0
35R-05-000-003				1	1	10	2			2											1(?)											16
35R-05-049-052					1(?)	1																										1
35R-05-101-103						4		1																								5
35R-06-000-003						2	1	1(?)		1																						4
35R-06-050-053																																0
35R-06-100-102						6	1	1														1										9
35R-CC-014-016						4		2														1										7
Total	0	1	0	1	1	37	6	6	1	6	0	0	0	0	1	0	0	0	0	0	0	9	0	1	0	0	0	0	0	0	0	70
%	0	1.429	0	1.429	1.429	52.86	8.571	8.571	1.429	8.571	0	0	0	0	1.428571429	0	0	0	0	0	0	12.86	0	1.429	0	0	0	0	0	0	0	100
36R-01-000-004						3																2										5
36R-01-049-052						1																1		1								3
36R-01-100-103						2				2																2						6
36R-02-000-003						2																										2
36R-02-050-053																																0
36R-02-101-104																																0
36R-03-000-002																																0
36R-03-052-055						2				1														1	1							5
36R-03-105-107						5		1		1															1							8
36R-04-000-003						4																1			1							6
36R-04-049-053						4																1			1	2						8
36R-04-099-102																					1(?)				1(?)							0
36R-05-000-003																																0
36R-05-050-054						1																										1
36R-05-100-103						2																										2

Table 1 (cont). Distribution of planktonic foraminifera from Site #998.

	Foraminfera ID	36R-06-000-003	36R-06-050-052	36R-CC-008-010	Total	%	37R-01-002-004	37R-01-049-052	37R-01-097-102	37R-02-000-003	37R-02-050-053	37R-02-099-103	37R-03-000-004	37R-03-049-052	37R-03-098-101	37R-04-000-004	37R-04-049-051	37R-04-100-103	37R-05-000-003	37R-05-051-054	37R-05-102-105	37R-06-003-005	37R-CC-009-012	Total	%	Total
Acarinina	*aspensis (?)*				0	0																		0	0	5
	bullbrooki		1		1	0.013						1	1								2		1	5	6.329	71
	collactea				0	0																		0	0	34
	coalengensis				0	0																		0	0	3
	cuneicamerata		1		1	0.013																		0	0	7
	pentacamerata	3	5	7	41	0.513			3	2		3		1				1		2	1		3	16	20.25	210
	praetopilensis				0	0																		0	0	184
	primitiva				1	0.013														1				1	1.266	15
	pseudotopilensis				0	0																		0	0	1
	quetra		4		8	0.1		1		1		1											1	4	5.063	18
Astrorotalia	*palmerae (?)*				0	0																		0	0	7
Globigerinatheka	*kugleri*				0	0																		0	0	31
	mexicana				0	0																		0	0	42
	subconglobata				0	0																		0	0	60
Globoturborotalita	*bassriverensis*				0	0																		0	0	32
Guembelitriodies	*nuttalli*				0	0																		0	0	25
Hantkenina	*liebusi*				0	0																		0	0	2
Igorina	*broedermanni*				0	0																		0	0	1
Parasubbotina	*eoclava*				0	0																		0	0	1
Praemurica	*lozanoi*				0	0																		0	0	3
'Pseudoglobigerinella	*bolivariana (?)*				0	0																		0	0	2
Morozovella	*aragonensis*	1	2	1	9	11.25		2				2								2			3	9	11.39	129
	caucasica				0	0																		0	0	6
	crater				2	2.5																		0	0	8
	formosa	1	1	2	8	10	1(?)	6	4	6		1	1		1	3	2			5	3		2	34	43.04	43
	subbontinae	3	2		9	11.25	1(?)	3	1	3										2	1			10	12.66	19
Subbotina	*corpulenta*				0	0																		0	0	9
	crociapertura				0	0																		0	0	2
	eocaena				0	0																		0	0	83
Turborotalia	*frontosa*				0	0																		0	0	22
	possagnoensis (?)				0	0																		0	0	4
	Total #	8	16	10	80	100	0	12	8	12	0	8	2	1	1	3	2	1	0	12	7	0	10	79	100	1079

4. Discussion

Biostratigraphy of Site 998

The correlation of the early to middle Eocene section of Site 998 with the planktonic foraminiferal biozonations of Wade et al. (2011) (Figure 9) is shown in Figure 11. The lower section of this study interval, cores 37R and part of 36R (19.2 m), is correlated with the *Morozovella aragonensis/ Morozovella subbotinae* Concurrent-range Zone (E5). Biozone E5 is recognized by the co-occurrences of the LO of *Morozovella aragonensis* and the HO of *Morozovella subbotinae*.

The middle of core 35R through the upper half of core 36R (9.6 m) is correlated to *Acarinia pentacamerata* Partial-range Zone (E6). This zone is defined by the partial range between the HO of *Morozovella subbotinae* and the LO of *Acarinina cuneicamerata*. The HO of *Acarinina quetra* and the HO of *Morozovella formosa* are used to help define the upper boundary of E6 and the bottom of E7a.

The middle of core 33R through the middle of 35R (19.2 m) is correlated to the Subzone E7a, *Acarinina cuneicarmerata* Lowest Occurrence. Wade et al. (2011) has defined this zone as the LO of the taxon *Acarinina cuneicamerata* and the LO of *Turborotalia frontosa*. The LO of *Acarinina pratetopilensis* is also used for a more defined bottom boundary of E7 and the top boundary of E6.

The middle of core 32R though the middle of core 33R (9.6 m) is correlated to the Subzone E7b, *Turborotalia frontosa* Lowest Occurrence. Wade et al. (2011) defined this zone as the LO of the taxon *Turborotailia frontosa* and the LO of *Guembelitrioides nuttalli.*

The middle of core 32R through the middle of core 35R (28.8 m) represents zone E7, *Acarinina cuneicamerata* Lowest Occurrence Zone. This zone is defined by the biostratigraphic interval between the LO of the taxon *Acarinina cuneicamerata* and the LO of *Guembelitroides nuttalli.* Zone E7 can be broken up into two subzones, E7b, *Turborotalia frontosa* lowest occurrence, and E7a, *Acarinina cuneicamerata* lowest occurrence.

The top of core 29R through the middle of core 32R (38.5 m) is correlated to the *Guembelitrioides nuttalli* Lowest-occurrence Zone (E8). E8 is characterized by the LO of *Guembelitrioides nuttalli* and *Globigerinatheka kugleri.* The LO of *Globigerinatheka subconglobata* and the HO of *Morozovella caucasica* are also used for a more defined E8 interval.

The upper most 9.7 m of this study interval (core 28R) is correlated with the *Globigerinatheka kugleri/Morozovella aragonensis* Concurrent-range Zone (CRZ) (E9). E9 is categorized by the concurrent range between the lowest occurrence (LO) of *Globigerinatheka kugleri* and the highest occurrence (HO) of *Morozovella aragonensis.* Both the LO of *Turborotalia possagnoensis* and the LO of *Globigerinatheka mexicana* are noted to in E9 and are found in core 28R.

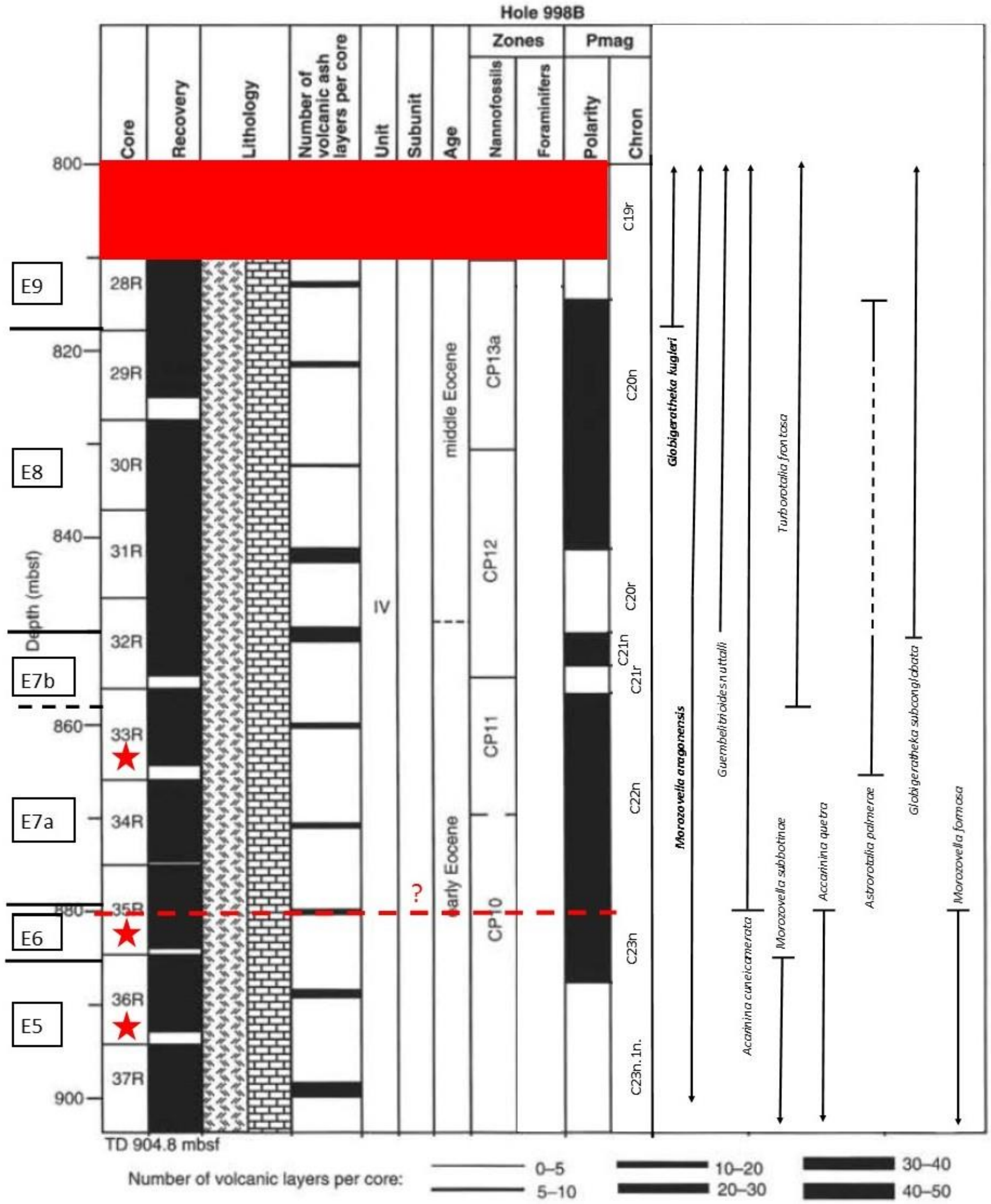

Figure 9. Biostratigraphic and chronostratigraphic column for Site #998. Modified form Scientific Shipboard Party (1997c). The red stars note where bethink foramina were found. The red box is covering core 27R, which was not sampled for this study.

Magnetostratigraphy

Based on the data collected in this study, the biozone E7/E6 boundary has been moved further down hole from 855 mbsf to 879.5 mbsf. Some of the inconsistences with the nannofossil events also correlate to inconsistences with the foraminifera data. There is one chron missing from the lower section of the study area, C22r. Chron C22r is found in E7 and helps in dividing E7a and E6. E7's subzones are also classified by the LO of *T. frontosa*, although this species is not as abundant as other foraminifera identified in this study, a tentative boundary can be drawn in for E7's subzones. The biozone E8 starts in a reversal (C20r), but according to the data collected E8 starts in a normal (C21n) (Figure 10). This could also be said with biozone E9. E9 ends in a reversal (C20r) but according to the data collected E9 ends in normal (C20n) (Figure 10). The magnetostratigraphy of the bottom most portion of Site 998 correlates to the Shipboard Scientific Party's (1997c) magnetostratigraphy. From C22n and up-hole, the chron correlation has re-interpreted to better represent the planktonic foraminifera biostratigraphy.

There are several possibilities that may have led to the stratigraphic inconsistences discussed above. These possibilities are as followed: preservation, paleoecology, section of missing core, sedimentation rates, volcanic ash layers, and unconformities. With more a detailed biostratigraphic framework interpreted from the data in this study, I have recalibrated the previous placement of the magnetostratigraphy from the Scientific Shipboard Party with the new and magnetostratigraphy (Figure 10). I have also redefined the previous biozones from Site 998 to better represent the data collected.

There were six planktonic foraminifera species identified in which their stratigraphic ranges are inconsistent with their known stratigraphic ranges: *Acarinina aspensis*, *Acarinina* *bullbrooki*, *Acarinina pentacamerata, Acarinina primativa*, *Astrorotalia palmerae*, and *Morozovella caucasia* (Person et. al., 2005). *Acarinina aspensis (?)* is found at the bottom of E9 and the top of E8. This is inconsistent with the known stratigraphic range, lower E7, and the magnetic data. *Acarinina bullbrooki* is noted from E11-E7. This known stratigraphic range is inconsistent with what has been established in the data as well as the magnetic data. *Acarinina pentacamerata* has been identified in the lower section of E9. This is inconsistent with the known stratigraphic range, E7-E5, and magnetic data. *Acarinina primitiva* has a known stratigraphic range of lower E7. This is inconsistent with the data analysis of the study interval. *Acarinina primitiva* has only been found in E9. *Astrorotalia palmerae* has been identified in the bottom of E9 and the top most section of E8, which is inconsistent with the known stratigraphic range, E7, and the magnetic data. *Morozovella caucasica* is found from the top of E8 to E7a. This is inconsistent with the established stratigraphic range, E8-E6, as well as the magnetic data.

These six foraminifera species have not been correlated to the geomagnetic time scale. Although, the first occurrence of *Acarinina bullbrooki* has been tied to the geomagnetic time scale the lowest occurrence has not. The lowest occurrence of this species is what was used in this study. Redefining the evolutionary record and the extinction events will help in linking paleoclimate records to determine biotic responses to climate change (Wade et al., 2011).

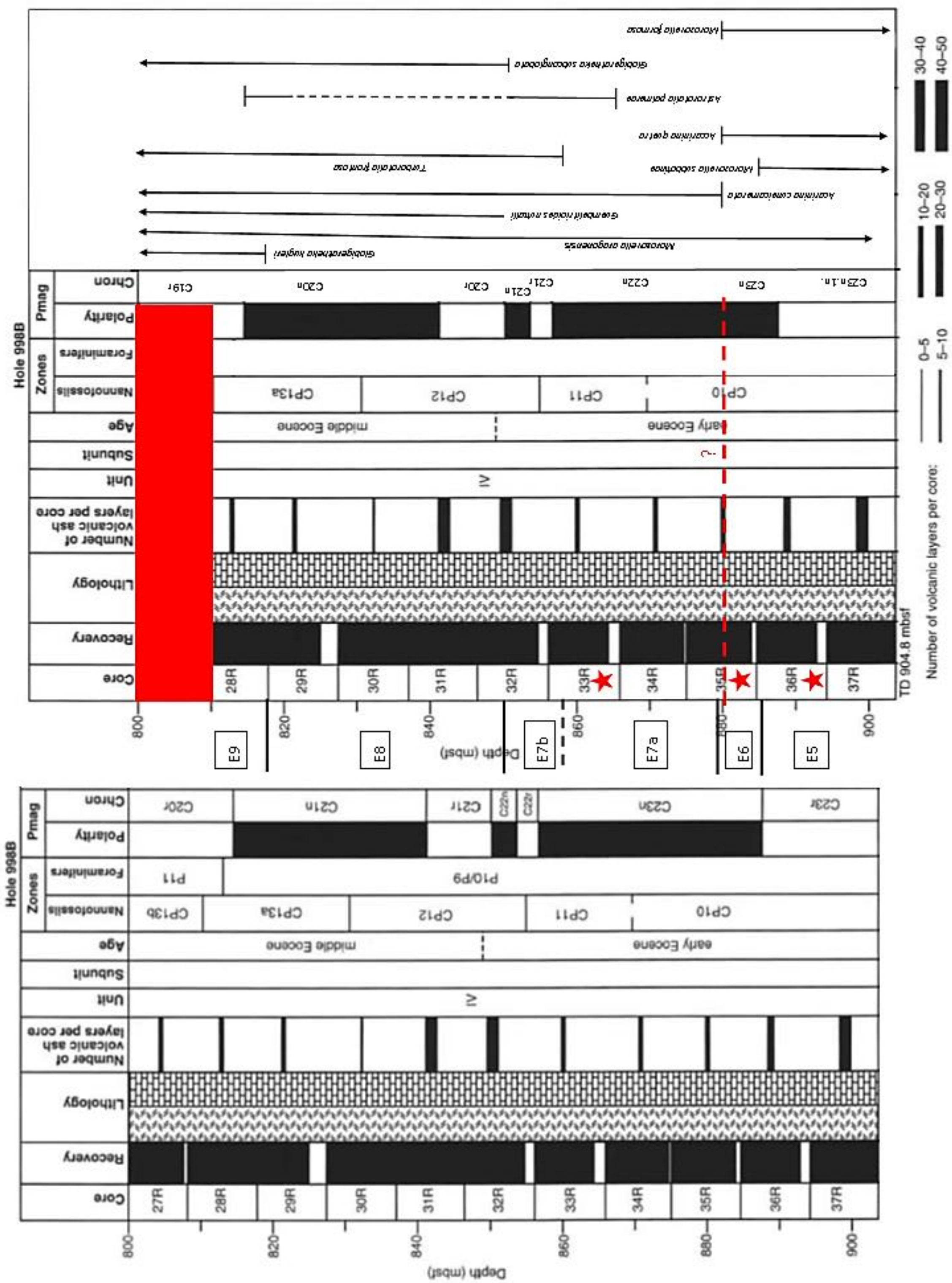

Figure 10. Biostratigraphic column of Site #998 with updated chronostratigraphy and the original chronostratigraphy for comparison. Modified from Shipboard Scientific Party (1997c).

Comparison to Previous Studies

Fluegeman (2007) used his preliminary analysis of Site 998 to interpret the planktonic foraminiferal biozones to be between E9-E5 (Figure 11a). He used the magnetostratigraphy defined by the Scientific Shipboard Party (1997c) to help constrain his data. In the analysis, Fluegeman (2007) suggested that the base of E9 correlates with C20r and the base of E8 stops short of C21r. E7 was noted to be a small portion of the interval with the biozone ending in C22n. The base of E6 ends in C23n with E5 is suggested to extend to the bottom of the interval.

Fluegeman (2007) used his preliminary data to interpret the planktonic foraminiferal biozones shown in Figure 11a. Figure 11b illustrates the interpretation of the planktonic foraminiferal biozones for Site #998 in this study. Using the data collected the correlations have been changed. E9 and E8 are the only two biozones that closely match with Fluegeman (2007). Biozones E7 has been significantly changed resulting in both E6 and E5 showing up lower in the core. The range of E6 has become slightly smaller due to the enlargement of E7.

Chezem (2012) looked at the planktonic foraminifera ratios in order to understand the physical and biological paleoceanographic parameters in Western Caribbean. Planktonic foraminifera ratios are found by dividing the total count amount of genera's *Morozovella* (m) by non-*Morozovella* (nm), m/nm ratio. Both *Morozovella* and *Acaranina* inhabit the warm mixed shallow layer in the tropical and subtropical oceans. But *Morozovella's* are known to be associated with tropical waters where as *Acaranina's* are known to be associated with subtropical/temperate waters. Using the ratios of these two genera a curve can be created to show the warming and cooling for ocean waters.

By using the planktonic foraminifera ratios, she noted that there were periods of episodic warming occurring throughout the Lutetian, the Early Middle Eocene Transition (EMET), and into early Ypresian. Chezem (2012) suggested that these warming periods may be due to a regional hyperthermal event. By using the foraminifera ratios and the *Tau*, there is an indication of a warming event across the Western Caribbean during the EMET (Chezem, 2012). *Tau* is defined by the total number of foraminifera species times the percentage of planktonic. *Tau* is used as an indicator of changes in water mass properties, such as water temperature, salinity, oxygen, nutrients, etc. An increase in *Tau* values suggests episodic rising sea level during the Lutetian, though the EMET, and into the Ypresian (Chezem, 2012).

Fluegeman (2007) and Chezem (2012) suggested from their data on planktonic assemblages of both morozovellids and subbotinids that, from the Ypresian though the Lutetian, there were fluctuations in the water temperature, shifting from warmer periods to cooler periods. In this study, the data collected supports the conclusions drawn from Fluegeman (2007) and Chezem (2012).

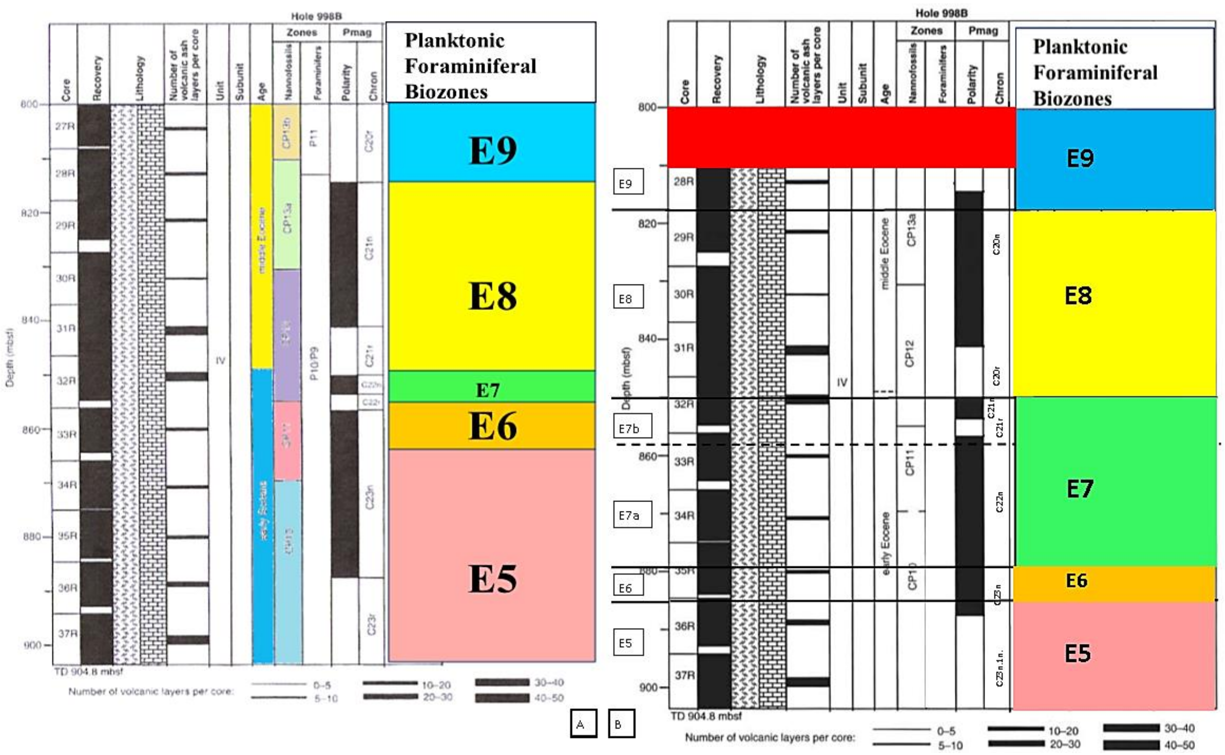

Figure 11. Comparison of Fluegeman (2007) (a) planktonic foraminiferal biozonations and the biozonations interpreted from this study on Site #998 in the Caribbean Sea (b).

El Cobre Group, Sierra Maestra, Cuba

When Lewis and Straczek (1955) described the El Cobre Group Formation they stated that it is one of the most important stratigraphic units in the south-central Oriente area because it is the most widespread, several times thicker and has the greatest economic use. The San Luis Formation overlies the El Cobre Group conformably throughout most of the Sierra Maestra. The El Cobre Group Formation overlies the Habana Formation and the older rocks with an angular unconformity in the Nipe-Cristal Highlands but the base of the El Cobre Group Formation is not noted else were in the region (Lewis and Straczek, 1955). The El Corbre Group Formation consists of volcanic rocks that are interbedded with secondary sedimentary rocks. The limestones found in the El Cobre Group Formation are noted to be highly tuffaceous. Both the tuffs and the limestones are interbedded and grade laterally and vertically into each other (Lewis and Straczek, 1995). The limestones are lenticular and one of the most important lenticular limestones is the Charco Redondo limestone. This limestone is found in the upper most part of the El Cobre Group Formation (Lewis and Straczek, 1955). Larger foraminifera are the most common microfossil identified in the El Cobre Formation. Smaller foraminifera, coral, algae were also identified in this formation.

The most recent foraminifera study was done by Quintas-Caballero and Crespo-Carbrera (2003). There was no magnetostratigraphy done for the El Cobre Group for the 2003 study. This makes comparisons based on magnetostratigraphy diffcult. Both planktonic and benthic foraminifera were used to identify biozones. There were three biozone classifications used: Bolli (1957), Bolli and Cita (1960), and Beckam et al. (1969). This makes it a little more difficult to correlate El Cobre Group to ODP Site 998 because there is no magnetostratigraphy and there are so few studies done on planktonic foraminifera. Lewis and Straczek (1955) and Fluegeman (2007) also identified foraminifera in the El Cobre Formation. Both Lewis and Staczek (1955) and Quintas-Caballero and Crespo-Carbrera (2003) also used an older foraminifera taxonomy for the identification of species. This meant that the foraminifera species that were identified in their studies would need to be renamed based on the most recent classification.

Based on the re-naming of the planktonic foraminifera from Quintas-Caballero and Crispo-Cabrera (2003) and comparing foraminifera appearances form this study to theirs, there does appear to be some similarities between El Cobre Group, Sierra Maestra, Cuba and ODP-Leg 165- Site 998b. The lowest most section of the El Cobre Group correlates to E5 with the *Morozovella aragonensis*/*Morozovella subbotinae* Concurrent-Range zone (Quintas-Caballero and Crespo-Cabrera, 2003). This is due to the appearance of the planktonic foraminifera *Morozovella formosa*, *Morozovella aragonensis*, and *Morozvella subbotinae.* Site 998b lowest most section also correlates to E5. With the appearance of *Hantkenina alabamensis*, *Dentoglobigerina tripartita*, *Globigerinatheka kugleri*, *Subbontina senni*, *Acarinina rorhi*, and *Morozovelloides crassatus*; the suggested biozonation given by Fluegeman (2007) has been moved up to E13, *Morozovellodies crassatus* Highest-Occurrence zone (Figure 12).

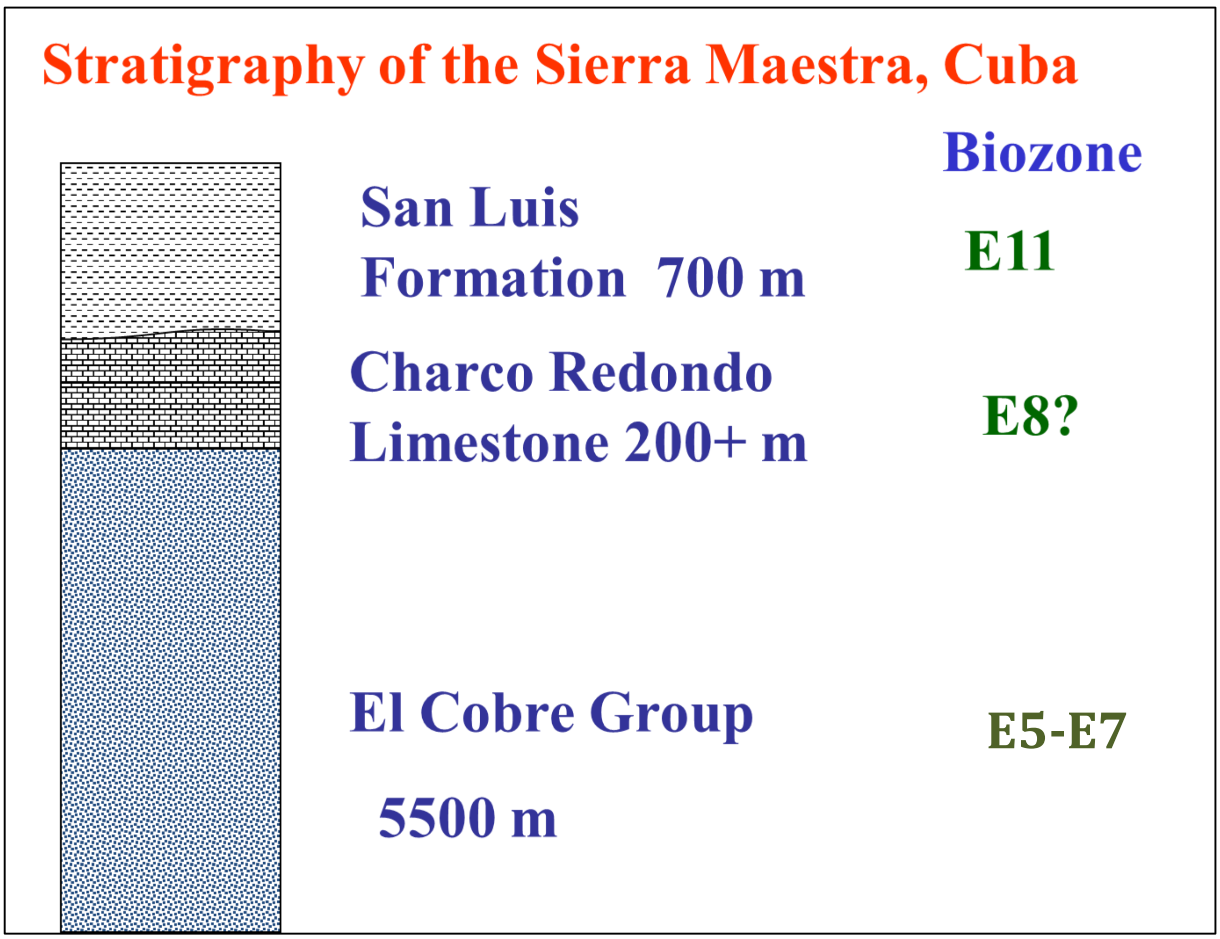

Figure 12. Stratigraphic column of the Sierra Maestra, Cuba based off of foraminifera. Provided by Dr. Rick Fluegeman (2007)

Lutetian Global Stratotype Section and Point (GSSP)

The GSSP for the Lutetian is located at Gorrondaxte Beach, northern Spain. The Lutetian GSSP is defined at 167.85 meters in the seaside cliff at Gorrondaxte Beach (Molina et al., 2011). During the Eocene, the Gorrondaxte section formed part of the bottom of a 1500 m deep marine gulf that opened into the Atlantic Ocean. Over 2300 m of the lower Ypresian and through the upper Lutetian were deposited in a deep marine environment. These deposits were then uplifted and tilted during the Alpine Orogeny as part of the western Pyrenees Cordillera (Molina et al., 2011). In the field, identification for this GSSP is a dark marly level where the lowest occurrence of calcareous nannofossil *Blackites inflatus* is noted (Molina et al., 2011).

As shown in Figure 14, the Lutetian GSSP is located on Chron 21r. Calcareous nannofossil *Blackites inflatus* is the primary microfossil used for biostratigraphic correlation to the magnetic time scale (Molina et al., 2011). While foraminifera *Turborotalia fontosa* is used for a secondary microfossil used to correlate to the magnetic time scale (Molina et al., 2011).

The Lutetian GSSP is tentatively confirmed and correlated to this study's biostratigraphic column. Chron C21r, which is used for the correlation of this GSSP, has been identified in Site 998. The GSSP is located in the lower most section of this chron. The microfossils used for the biostratigraphic correlation are either absent or not abundant enough in Site #998 and the Lutetian GSSP uses these specific microfossils to place the GSSP. I have used C21r to correlate the Lutetian GSSP to Site #998 and the Lutetian GSSP has also been tentatively placed on Site 998's biostratigraphic column (Figure 13).

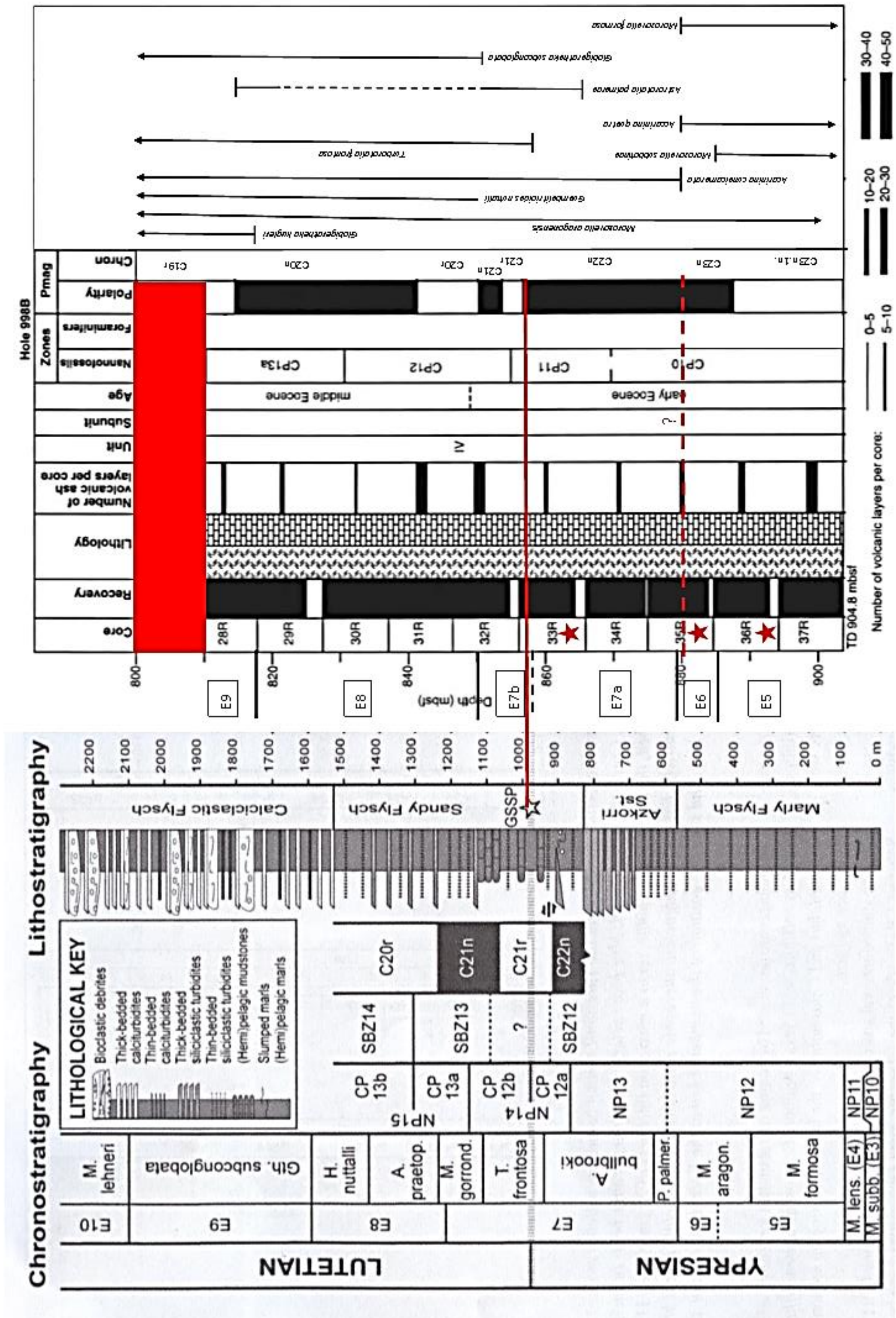

Figure 13. Correlation of the Lutetian GSSP to Site #998. The red star is the location of the Lutetian GSSP. The red line is showing the correlation and placement of the GSSP in Site #998.

6. Conclusions

- The magnetostratigraphy of Site 998 was re-correlated based off of the planktonic foraminifera. The magnetostratigraphy of the bottom most section of Site 998 correlates to Shipboard Scientific Party's (1997c) magnetostratigraphy. From C22n, the chron correlation has change to better represent the planktonic foraminifera biostratigraphy.

- Unable to resolve the issues with correlating E7's subzones to the cores due to there not being an abundance of the planktonic foraminifera *Turborotalia frontosa*. Based off of the reclassification of biozones from Wade et al. (2011), a cautious placement of E7b and E7a has been established on the Site #998 biostratigraphic column.

- Lutetian GSSP can be compared to Site #998 using Chron C21r. This will help in having a more precise understanding on the early to middle Eocene transition in the Caribbean region.

- The data collected is consistent with other previous microfossil data from Site #998. The inconsistences on the other microfossil data shows the same inconsistences with the planktonic foraminiferal data collected in this study, such as absent or little microfossils of a known species for particular biozone.

- The El Cobre Group, Sierra Mastra, Cuba does appear to correlate to ODP Site 998. This is based off of the appearances of the planktonic foraminifera *Morozovella aragonensis*, *Morozovella subbontinae, Turborotalia frontosa, Acarinina bullbrooki,* and *Globigerinatheka kugleri.* The oldest part of the El Cobre Group is correlated to E5 with the appearance of *Morozovella aragonensis* and *Morozovella subontinae.* The youngest part of the El Cobre Group is correlated to E13 with the appearance of *Hantkenina alabamensis Globigerinatheka kugleri, Subbontina senni, Acarinina rorhi,* and *Morozovelloides crassatus.*

- Fluegeman (2007) used preliminary data to interpret where the planktonic foraminiferal biozone might be. Using the data collected in this study, I have created a more detailed biostratigraphic column in which biozones E7-E5 have been significantly altered and E9-E8 have not change that much.

- The data collected from this study confirms the conclusions drawn from Chezem (2012) and Fluegeman (2007).

- Potential future graduate project ideas. Work on other deep-sea cores and in Cuba, Jamaica, and throughout the Caribbean region. There is also the potential for future graduate work to create a high-resolution biostratigraphic and magnetostratigraphic column on El Cobre Group, Sierra Maestra, Cuba.

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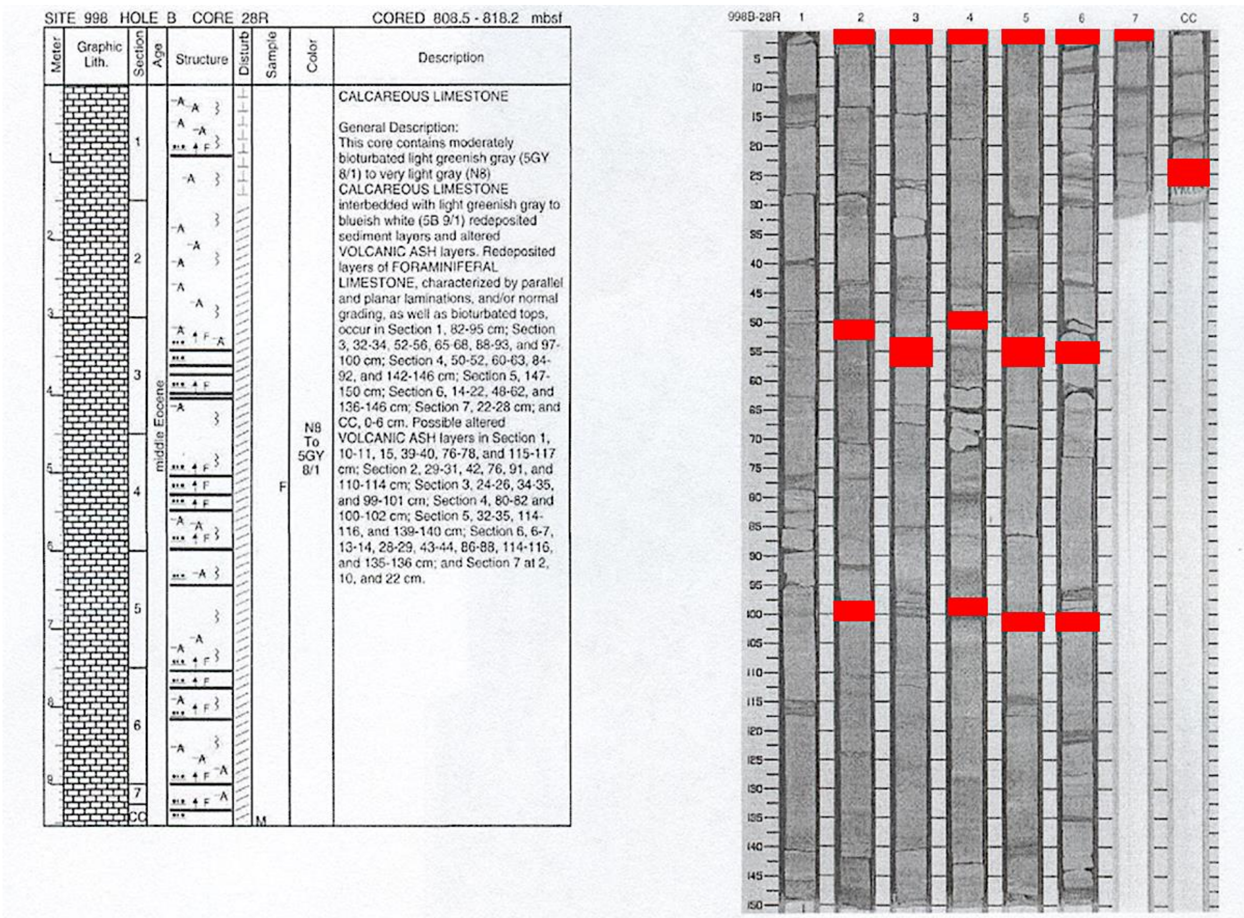
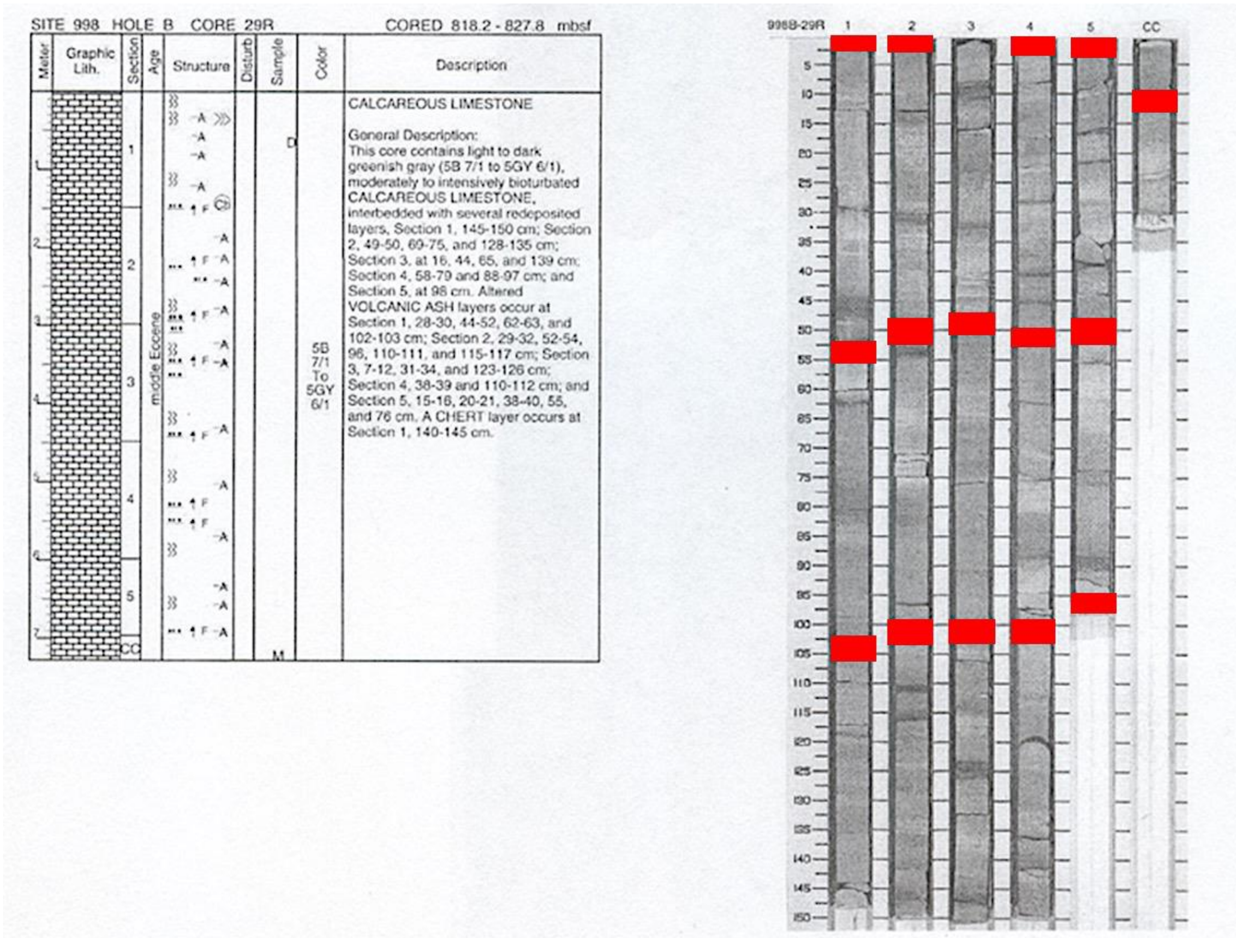
Appendix A

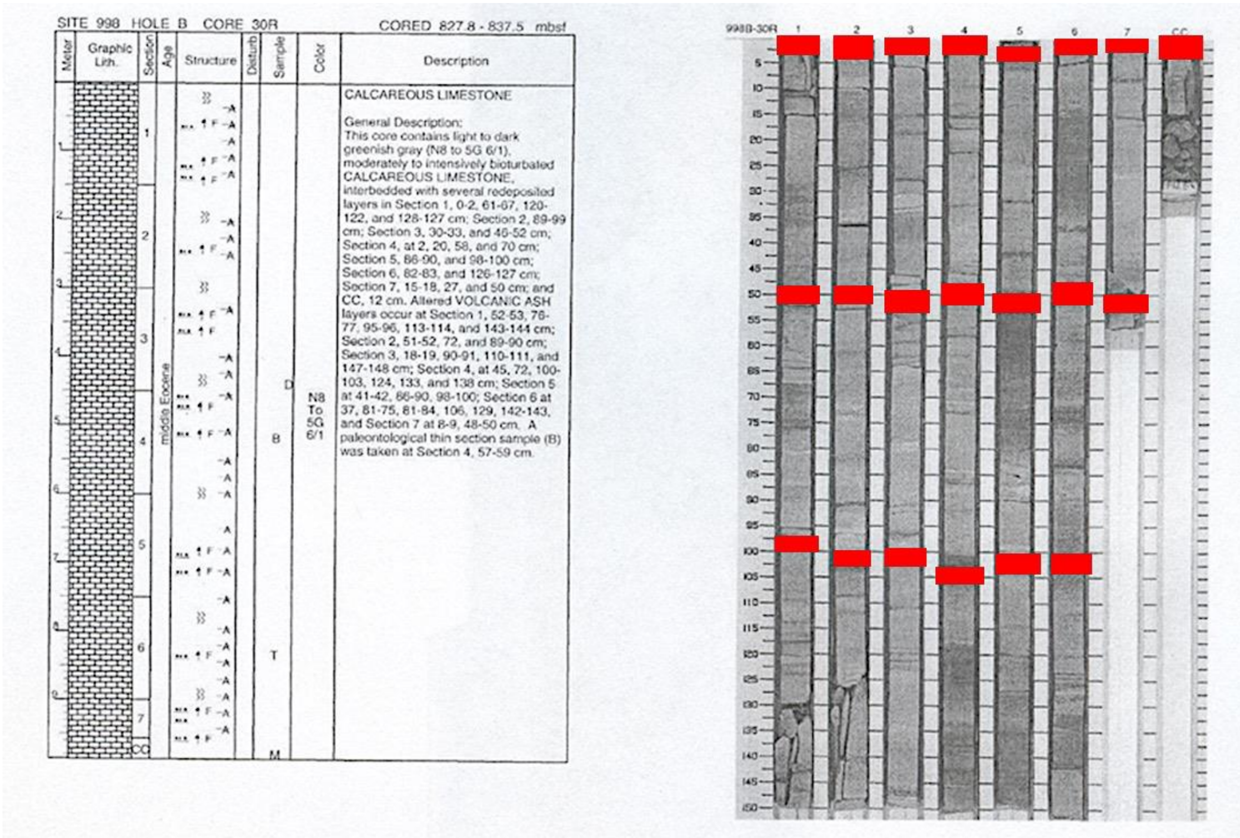
Shipboard Core Description

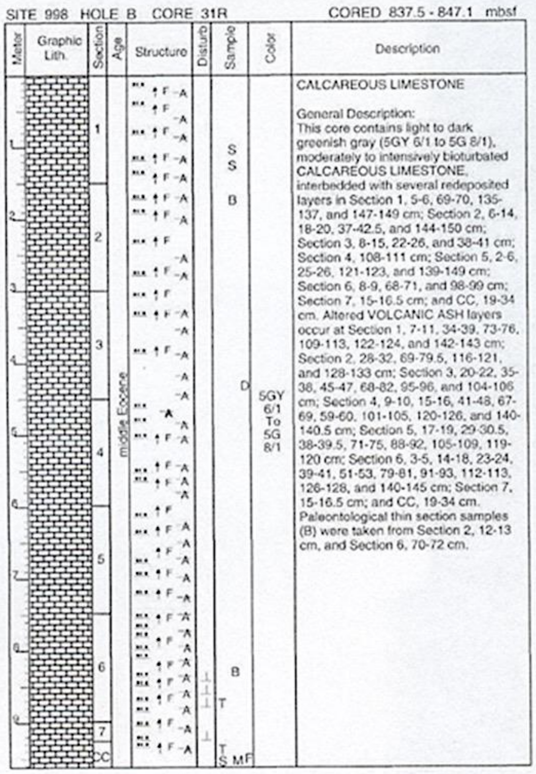
The following figures are the shipboard core descriptions for cores 28R-37R. These core descriptions were taken from the ODP website under the Leg 165 initial reports section. Sample locations are marked in red.





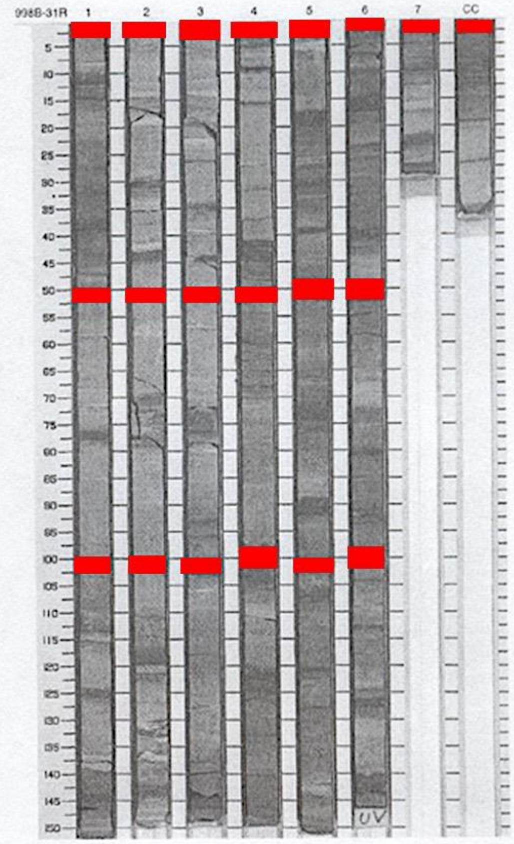
SITE 998 HOLE B CORE 29R
CORED 818.2 - 827.8 mbsf
Meter
Graphic Lith.
Section
Age
Structure
Disturb
Sample
Color
Description
middle Eocene
5B 7/1 To 5GY 6/1
CALCAREOUS LIMESTONE
General Description:
This core contains light to dark greenish gray (5B 7/1 to 5GY 6/1), moderately to intensively bioturbated CALCAREOUS LIMESTONE, interbedded with several redeposited layers, Section 1, 145-150 cm; Section 2, 49-50, 69-75, and 128-135 cm; Section 3, at 16, 44, 65, and 139 cm; Section 4, 58-79 and 88-97 cm; and Section 5, at 98 cm. Altered VOLCANIC ASH layers occur at Section 1, 28-30, 44-52, 62-63, and 102-103 cm; Section 2, 29-32, 52-54, 96, 110-111, and 115-117 cm; Section 3, 7-12, 31-34, and 123-126 cm; Section 4, 38-39 and 110-112 cm; and Section 5, 15-16, 20-21, 38-40, 55, and 76 cm. A CHERT layer occurs at Section 1, 140-145 cm.
998B-29R
1
2
3
4
5
CC

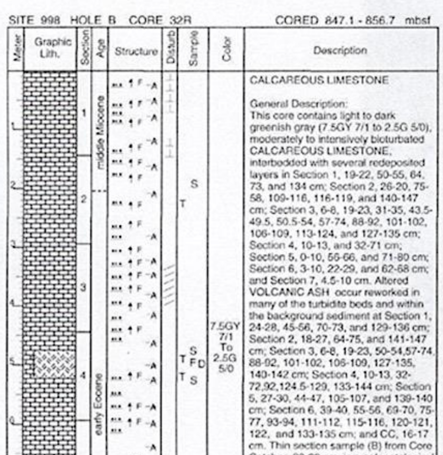

SITE 998 HOLE B CORE 30R
CORED 827.8 - 837.5 mbsf
Meter
Graphic Lith.
Section
Age
Structure
Disturb
Sample
Color
Description
CALCAREOUS LIMESTONE
General Description:
This core contains light to dark greenish gray (N8 to 5G 6/1), moderately to intensively bioturbated CALCAREOUS LIMESTONE, interbedded with several redeposited layers in Section 1, 0-2, 61-67, 120-122, and 128-127 cm; Section 2, 89-99 cm; Section 3, 30-33, and 46-52 cm; Section 4, at 2, 20, 58, and 70 cm; Section 5, 86-90, and 98-100 cm; Section 6, 82-83, and 126-127 cm; Section 7, 15-18, 27, and 50 cm; and CC, 12 cm. Altered VOLCANIC ASH layers occur at Section 1, 52-53, 76-77, 95-96, 113-114, and 143-144 cm; Section 2, 51-52, 72, and 89-90 cm; Section 3, 18-19, 90-91, 110-111, and 147-148 cm; Section 4, at 45, 72, 100-103, 124, 133, and 138 cm; Section 5 at 41-42, 86-90, 98-100; Section 6 at 37, 81-75, 81-84, 106, 129, 142-143, and Section 7 at 8-9, 48-50 cm. A paleontological thin section sample (B) was taken at Section 4, 57-59 cm.
middle Eocene
N8 To 5G 6/1
998B-30R



SITE 998 HOLE B CORE 31R CORED 837.5 - 847.1 mbsf

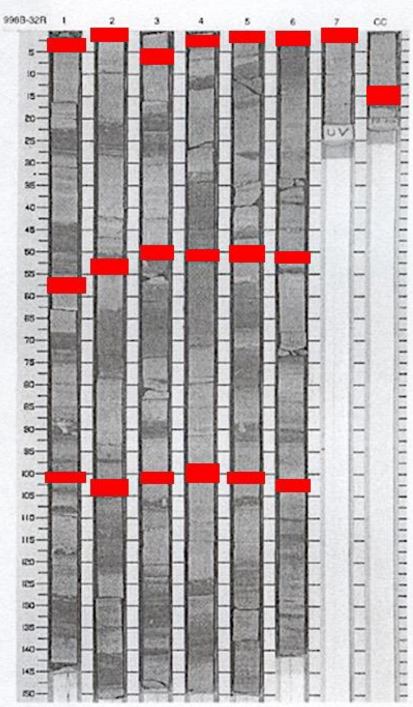
Meter	Graphic Lith.	Section	Age	Structure	Disturb	Sample	Color	Description
		1, 2, 3, 4, 5, 6, 7, CC	middle Eocene			S, S, B, D, B, T, T, S, M, F	5GY 6/1 To 5G 8/1	CALCAREOUS LIMESTONE General Description: This core contains light to dark greenish gray (5GY 6/1 to 5G 8/1), moderately to intensively bioturbated CALCAREOUS LIMESTONE, interbedded with several redeposited layers in Section 1, 5-6, 69-70, 135-137, and 147-149 cm; Section 2, 6-14, 18-20, 37-42.5, and 144-150 cm; Section 3, 8-15, 22-26, and 38-41 cm; Section 4, 108-111 cm; Section 5, 2-6, 25-26, 121-123, and 139-149 cm; Section 6, 8-9, 68-71, and 98-99 cm; Section 7, 15-16.5 cm; and CC, 19-34 cm. Altered VOLCANIC ASH layers occur at Section 1, 7-11, 34-39, 73-76, 109-113, 122-124, and 142-143 cm; Section 2, 28-32, 69-79.5, 116-121, and 128-133 cm; Section 3, 20-22, 35-38, 45-47, 68-82, 95-96, and 104-106 cm; Section 4, 9-10, 15-16, 41-48, 67-69, 59-60, 101-105, 120-126, and 140-140.5 cm; Section 5, 17-19, 29-30.5, 38-39.5, 71-75, 88-92, 105-109, 119-120 cm; Section 6, 3-5, 14-18, 23-24, 39-41, 51-53, 79-81, 91-93, 112-113, 126-128, and 140-145 cm; Section 7, 15-16.5 cm; and CC, 19-34 cm. Paleontological thin section samples (B) were taken from Section 2, 12-13 cm, and Section 6, 70-72 cm.





SITE 998 HOLE B CORE 32R CORED 847.1 - 856.7 mbsf

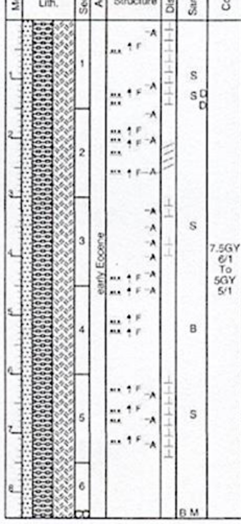
Meter	Graphic Lith.	Section	Age	Structure	Disturb	Sample	Color	Description
		1, 2, 3, 4, 5, 6, 7, CC	middle Miocene / early Eocene			S, T, S, T, F, D, T, S, B, M	7.5GY 7/1 To 2.5G 5/0	CALCAREOUS LIMESTONE General Description: This core contains light to dark greenish gray (7.5GY 7/1 to 2.5G 5/0), moderately to intensively bioturbated CALCAREOUS LIMESTONE, interbedded with several redeposited layers in Section 1, 19-22, 50-55, 64, 73, and 134 cm; Section 2, 26-20, 75-58, 109-116, 116-119, and 140-147 cm; Section 3, 6-8, 19-23, 31-35, 43.5-49.5, 50.5-54, 57-74, 88-92, 101-102, 106-109, 113-124, and 127-135 cm; Section 4, 10-13, and 32-71 cm; Section 5, 0-10, 56-66, and 71-80 cm; Section 6, 3-10, 22-29, and 62-68 cm; and Section 7, 4.5-10 cm. Altered VOLCANIC ASH occur reworked in many of the turbidite beds and within the background sediment at Section 1, 24-28, 45-56, 70-73, and 129-136 cm; Section 2, 18-27, 64-75, and 141-147 cm; Section 3, 6-8, 19-23, 50-54,57-74, 88-92, 101-102, 106-109, 127-135, 140-142 cm; Section 4, 10-13, 32-72,92,124.5-129, 133-144 cm; Section 5, 27-30, 44-47, 105-107, and 139-140 cm; Section 6, 39-40, 55-56, 69-70, 75-77, 93-94, 111-112, 115-116, 120-121, 122, and 133-135 cm; and CC, 16-17 cm. Thin section sample (B) from Core Catcher, 20-22 cm, is a paleontological thin section.



457

SITE 998

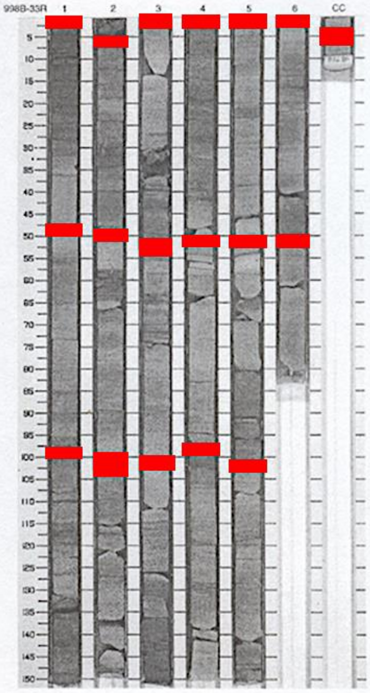
SITE 998 HOLE B CORE 33R CORED 856.7 - 866.3 mbsf



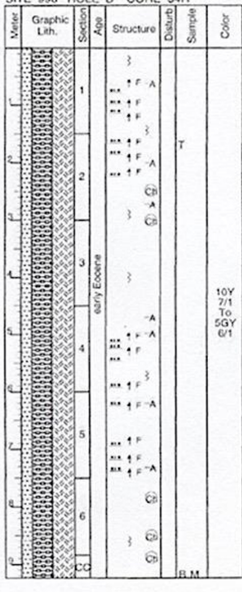
Description

CALCAREOUS VOLCANICLASTIC MIXED SEDIMENT

General Description:
This core contains light to dark greenish gray (7.5GY 6/1 to 2.5GY 5/1), slightly bioturbated CALCAREOUS VOLCANICLASTIC MIXED SEDIMENT, interbedded with several thin redeposited layers of CALCAREOUS LIMESTONE turbidites in Section 1, 35-44.5 and 94-95 cm; Section 2, 38-40 and 54.5-56.5 cm; Section 5,19-23, 64-66, and 105-108 cm. Altered VOLCANIC ASH layers mixed with carbonate occur reworked in turbidite beds in Section 1, 114.5 - 120 and 120-126 cm; Section 2, 29-35.5, 58-65, and 100-102 cm; Section 3, 111-113 and 125-130 cm; Section 5, 19-23, 64-66, and 105-108 cm; and Section 6, 4-6, 12-13, 32-36, and 56-57 cm, and within the background sediment at Section 1, 7-9, 55-56, and 134-135 cm; Section 2, 0-6, and 111-112 cm; Section 3, 13-15, 31-36, 64-66, and 72 cm; and Section 6, 19-20 cm. Four XRD Samples were taken from Section 1 at 111-112, 116-117, 119-120, and 121-122 cm. Paleontological thin Section samples (B) were taken from Section 4, 56-57, and Core Catcher, 9-11 cm.



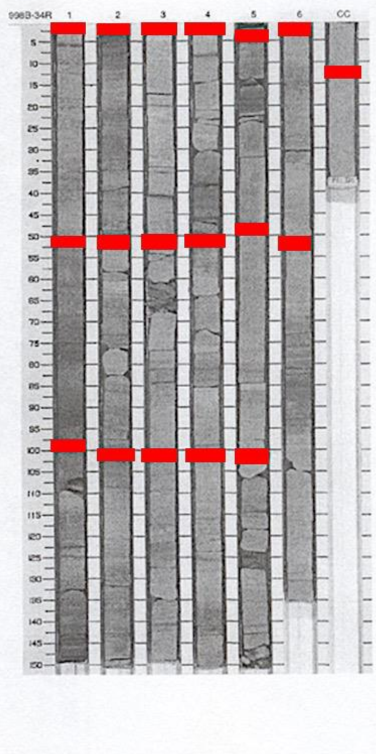
SITE 998 HOLE B CORE 34R CORED 866.3 - 875.9 mbsf



Description

CALCAREOUS VOLCANICLASTIC MIXED SEDIMENT

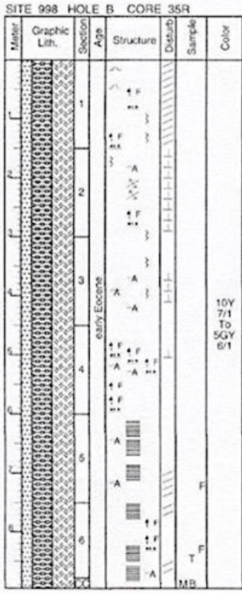
General Description:
This core contains light to dark greenish gray (10Y 7/1 to 5GY 6/1), slightly bioturbated CALCAREOUS VOLCANICLASTIC MIXED SEDIMENT, interbedded with several thin redeposited layers of CALCAREOUS LIMESTONE turbidites in Section 1, 71-73, 74-90, 90-103 cm; Section 2, 0-7, 7-15, and 57-64 cm; Section 4, 28-43, 49-52, 52-58, 78-85, 119-128, and 135-147 cm; and Section 5, 2-14, 75-85, 85-105, 110-112, 115-116, and 121-122 cm. Altered VOLCANIC ASH layers mixed with carbonate occur reworked in turbidite beds, Section 5, 2-14 cm, and within the background sediment in Section 1, 49-50 cm; Section 2, 42-60, and 110-112 cm; Section 4, 8, 38, and 45 cm; and Section 5, 123-127 and 148-150 cm. Incipient silicification layers occur in Section 2, 106-107, 117-119, and 126-127 cm; and Section 6, 28-33, 91-95, 98, 100, and 126-135 cm. Thin section sample (B) from Core Catcher, 37-39 cm, is a paleontological thin section.



SITE 998

490

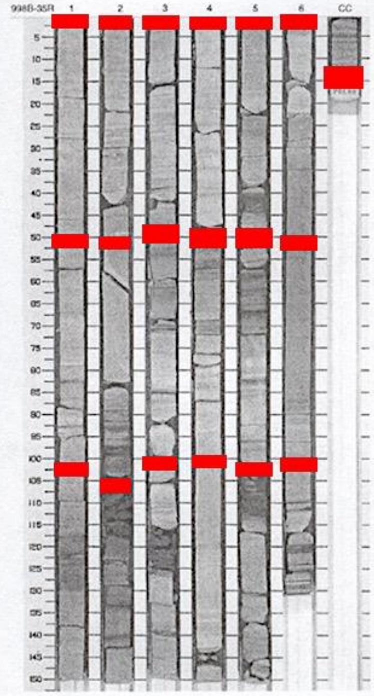
SITE 998 HOLE B CORE 35R CORED 875.9 - 885.5 mbsf



Description

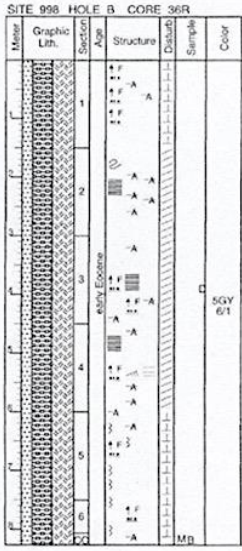
CALCAREOUS VOLCANICLASTIC MIXED SEDIMENT

General Description:
This core contains light to dark greenish gray (10Y 7/1 to 5GY 6/1), slightly bioturbated CALCAREOUS VOLCANICLASTIC MIXED SEDIMENT, interbedded with several thin redeposited layers of CALCAREOUS LIMESTONE, and reworked altered VOLCANIC ASH layers mixed with carbonate. These occur in Section 1, 40-80, and 138-150 cm; Section 2, 118-123 cm; Section 4, 47-54, 61-69, 72-78, and 95-144 cm; and CC, 0-3, and 5-10 cm. A contourite occurs at Section 2, 83-97 cm. The background sediment is frequently faintly laminated, and composed of interbedded sands, silts, and clays. Two fractures, infilled with clay, occur in Section 2, 45-85 cm. Altered VOLCANIC ASHES are frequent, occurring at Section 2, 31 cm; Section 3, at 60, 70, and 120 cm; Section 4, at 60 and 70 cm; Section 5, at 45 and 110 cm; and Section 6, 121-122 cm. Thin section sample (B) from Core Catcher, 16-18 cm, is a paleontological thin section.



SITE 998

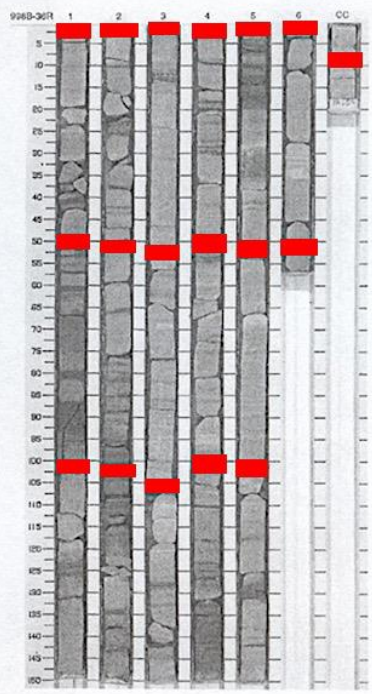
SITE 998 HOLE B CORE 36R CORED 885.5 - 895.1 mbsf



Description

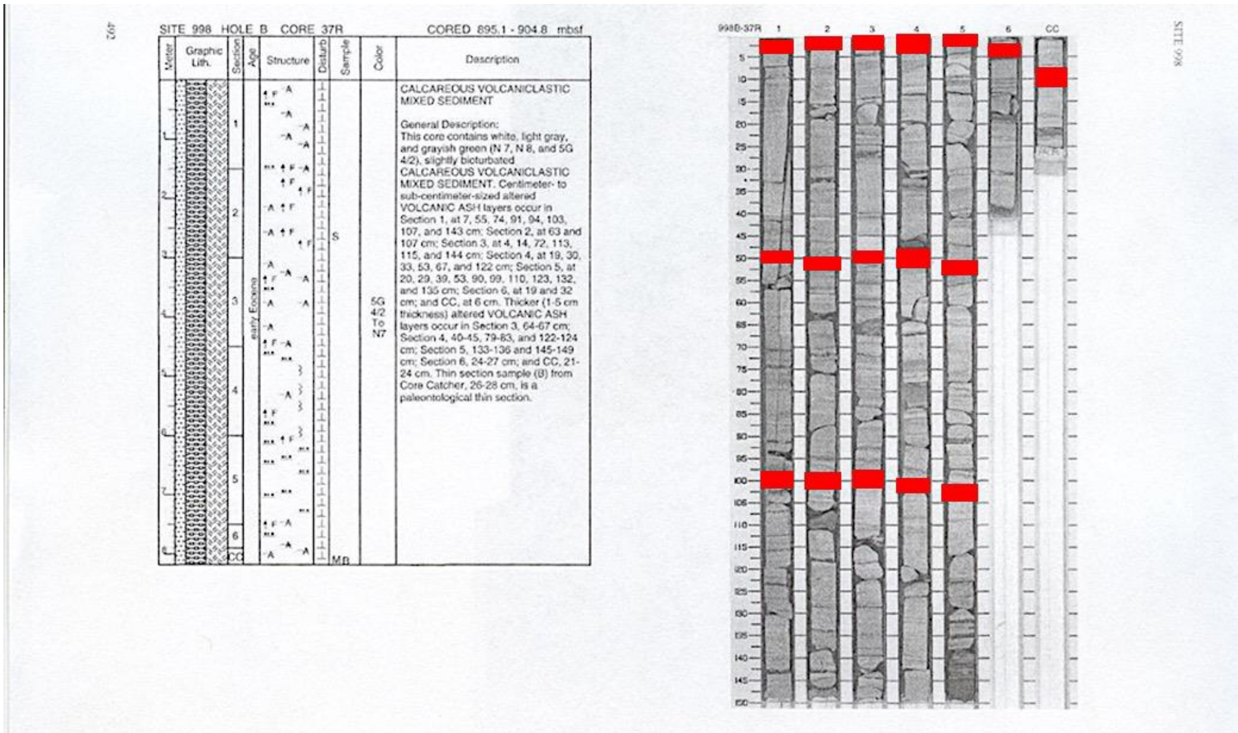
CALCAREOUS VOLCANICLASTIC MIXED SEDIMENT

General Description:
This core contains dark greenish gray (5GY 6/1), slightly bioturbated CALCAREOUS VOLCANICLASTIC MIXED SEDIMENT, interbedded with several thin redeposited layers of CALCAREOUS LIMESTONE, and reworked altered VOLCANIC ASH layers mixed with carbonate. Redeposited layers are located in Section 1, 20-30, 55-70, and 90-105 cm; Section 2, 5-15 cm; Section 3, 80-90 and 115-125 cm; Section 4, 20-67, 75-90, and 95-110 cm; Section 5, 70-75 cm; and Section 6, 25-35 cm. Altered VOLCANIC ASHES occur in Section 1, 40-41 and 60-61 cm; Section 2, 43-50, 65-95, and 109-112 cm; Section 3, 10-13, 107-109, and 141-143 cm; Section 4, 8-20, 111-112, 132-134, and 141-144 cm; and Section 5, 14-18 cm; CC, 13 cm. Thin section sample (B) from Core Catcher, 18-20, cm is a paleontological thin section.



491

SITE 998


SITE 998 HOLE B CORE 37R
CORED 895.1 - 904.8 mbsf
Meter
Graphic Lith.
Section
Age
Structure
Disturb
Sample
Color
Description
early Eocene
5G 4/2 To N7
CALCAREOUS VOLCANICLASTIC MIXED SEDIMENT
General Description:
This core contains white, light gray, and grayish green (N 7, N 8, and 5G 4/2), slightly bioturbated CALCAREOUS VOLCANICLASTIC MIXED SEDIMENT. Centimeter- to sub-centimeter-sized altered VOLCANIC ASH layers occur in Section 1, at 7, 55, 74, 91, 94, 103, 107, and 143 cm; Section 2, at 63 and 107 cm; Section 3, at 4, 14, 72, 113, 115, and 144 cm; Section 4, at 19, 30, 33, 53, 67, and 122 cm; Section 5, at 20, 29, 39, 53, 90, 99, 110, 123, 132, and 135 cm; Section 6, at 19 and 32 cm; and CC, at 6 cm. Thicker (1-5 cm thickness) altered VOLCANIC ASH layers occur in Section 3, 64-67 cm; Section 4, 40-45, 79-83, and 122-124 cm; Section 5, 133-136 and 145-149 cm; Section 6, 24-27 cm; and CC, 21-24 cm. Thin section sample (B) from Core Catcher, 26-28 cm, is a paleontological thin section.
998B-37R
CC

Appendix B

Table of Foraminifera Comments and Preservation States

Table 1. Foraminifera Comments and Preservation states of thin sections.

28R-02-000-003
Moderate-poor preservation
28R-02-050-053
Poor preservation
28R-02-099-102
poor preservation/ slide is a little too thick
28R-03-000-003
Poor preservation
28R-03-057-054
Poor preservation
28R-04-000-003
Poor preservation
28R-04-049-051
Very poor preservation/fragments
28R-04-098-100
Poor preservation
28R-05-000-002
Poor preservation
28R-05-054-057
Moderate preservation
28R-05-100-103
Moderate-Poor preservation

28R-06-000-003
turbidity flow(?)/Moderate-Poor preservation/Can see what looks like the disturbance of the forams on the surface from the flow
28R-06-054-056
Very poor- Poor preservation
28R-06-100-103
Moderate-Poor preservation/ fragments
28R-07-000-001
Poor preservation/too much debris for identification
28R-CC-023-026
Moderate-Poor preservation
29R-01-002-005
Poor preservation
29R-01-052-055
Moderate-Poor preservation
29R-01-103-106
Very poor preservation
29R-02-000-003
Moderate-Poor preservation/turbidity flow
29R-02-049-052
Very Poor-Poor preservation/turbidity flow/fragments
29R-02-100-103
Very poor- Poor preservation

29R-03-047-052
Very poor - Poor preservation
29R-03-103-106
Very poor preservation/fragments
29R-04-000-003
Very poor preservation
29R-04-050-053
Poor preservation
29R-04-100-103
Very poor - Poor preservation
29R-05-000-004
Very poor -poor preservation
29R-05-049-052
poor preservation
29R-05-096-098
Very poor preservation
29R-CC-010-013
Very poor preservation/little to no wall textures or structures/ recrystallized
30R-01-000-004
Poor preservation
30R-01-049-052
Poor preservation
30R-01-097-100

Poor preservation
30R-02-000-004
Poor preservation/turbidite flow?
30R-02-049-052
Very poor preservation
30R-02-100-104
Poor preservation
30R-03-000-003
Very poor preservation
30R-03-050-053
Moderate preservation
30R-03-100-103
Very Poor-Poor preservation
30R-04-000-003
Chlorite (lots)/Very poor preservation
30R-04-049-052
Poor preservation
30R-04-104-107
Very poor preservation/little to no forams/little to no wall structures or wall textures
30R-05-002-005
Very poor preservation
30R-05-050-053
Very poor preservation

30R-05-101-104
very poor to poor preservation/turbidity flow?
30R-06-000-003
Poor preservation
30R-06-049-053
Very poor-poor Preservation
30R-06-101-104
very poor preservation/little to no identifiable markers
30R-07-000-002
Moderate-poor preservation
30R-07-050-052
Very poor preservation/chlorite present
30R-CC-000-003
Moderate - poor preservation
31R-01-000-003
Poor preservation
31R-01-050-053
Very poor preservation/foram walls and structures are too degraded to identify
31R-01-100-103
Very poor preservation/forams have been recrystallized
31R-02-000-003
Very poor preservation/forams have been recrystallized
31R-02-050-053

Very poor preservation/forams have been recrystallized
31R-02-100-103
Very poor preservation/forams have been recrystallized
31R-03-000-004
Very poor preservation/forams have been recrystallized
31R-03-050-052
Very poor preservation/forams have been recrystallized
31R-03-100-103
Very poor preservation/ little to no identifiable forams/secondary recrystallization
31R-04-000-003
Very poor preservation/ little to no identifiable forams
31R-04-050-053
Very poor preservation/ little to no recognizable forms
31R-04-098-101
Very poor preservation/ little to no recognizable forms
31R-05-000-003
Very poor to poor preservation
31R-05-049-052
Very poor preservation
31R-05-100-102
Very poor preservation/ no identifiable features on the forams
31R-06-000-002
Very poor preservation/ no identifiable features on the forams

31R-06-049-051
Very poor preservation/no identifiable features on the forams
31R-06-099-101
Very poor preservation/ little to no identifiable features on the forams
31R-07-000-002
Some type of flow with siderite replacement/Very poor preservation
31R-CC-048-050
Very poor preservation/no identifiable features on the forams
32R-01-003-005
Poor- very poor preservation (left side of the slide)
32R-01-056-058
Poor preservation
32R-01-100-102
Very poor preservation/no identifiable features on the forams
32R-02-000-002
Very poor - Poor preservation
32R-02-047-049
Very poor preservation
32R-02-102-105
Very poor preservation/no identifiable features on the forams
32R-03-005-007
Very poor preservation/very little or no identifiable features on the forams
32R-03-048-051

Very poor preservation/ little to no identifiable features on the forams
32R-03-100-102
Shell fragments (very few)/Very poor preservation/ no identifiable features on the forams
32R-04-002-004
Very poor preservation/ no identifiable features on the forams
32R-04-050-052
Very poor preservation/no identifiable features on the forams/volcanic ash layers (?)
32R-04-099-101
Very poor preservation/no identifiable features
32R-05-000-002
Very poor preservation/no identifiable features
32R-05-049-051
Very poor- Poor preservation
32R-05-100-102
Very poor- Poor preservation
32R-06-000-003
Very poor preservation
32R-06-050-052
Poor- Moderate preservation
32R-06-101-103
Very poor preservation/recrystallization
32R-07-000-002
Very poor - Poor preservation

32R-CC-014-016
Very poor preservation
33R-01-000-002
Very poor preservation/ little to no identifiable features on the forams
33R-01-048-050
Turbidity flow/very poor- poor preservation
33R-01-098-100
Very poor preservation/ little to no identifiable features on the forams
33R-02-005-007
Very poor preservation/no identifiable wall features/benthics were found
33R-02-049-051
Poor preservation/ sometime of flow in the middle of the thin section (small turbidity?)
33R-02-099-105
Very poor- poor preservation/ little to no identifiable wall features
33R-03-000-003
Very poor preservation/ little to no identifiable features on the forams
33R-03-052-054
Very poor preservation/ little to no identifiable features on the forams
33R-03-100-102
Moderate- poor preservation
33R-04-000-002
Very poor preservation/ no identifiable features on the forams/ volcanic ash flow mixed with graded of forams

33R-04-050-052
Very poor preservation/ no identifiable features
33R-04-096-099
Very poor preservation/ no identifiable features
33R-05-000-003
Very poor preservation/ no identifiable features
33R-05-050-053
Very poor preservation/ no identifiable features
33R-05-101-103
Very poor preservation/ no identifiable features
33R-06-000-002
Very poor preservation/ little to no identifiable features
33R-06-050-053
Very poor preservation/ no identifiable forams
33R-CC-004-006
Very poor preservation/ little to no identifiable forams
34R-01-000-003
Very poor preservation/ small fine grading of sediment/ little to no identifiable features
34R-01-050-052
Very poor preservation/ no identifiable forams
34R-01-098-100
Very poor preservation/ no identifiable forams
34R-02-000-002

Very poor preservation/ no identifiable forams
34R-02-050-053
Very poor preservation/ no identifiable forams
34R-02-100-102
Very poor preservation/ no identifiable forams
34R-03-000-002
Poor- very poor preservation
34R-03-050-053
Very poor preservation/no identifiable forams
34R-03-100-102
Very poor-poor preservation/little identifiable forams to the top of the thin section
34R-04-000-002
Very poor preservation/little to no identifiable forams
34R-04-050-052
Very poor preservation/no identifiable forams
34R-04-100-102
Very poor preservation/no identifiable forams
34R-05-003-005
Very poor preservation/no identifiable forams
34R-05-048-050
Very poor preservation/no identifiable forams
34R-05-100-104
Turbidity flow/hard to distinguish between different forams

34R-06-000-004
Very poor preservation/ little to no identifiable forams
34R-06-051-054
Very poor preservation/ little to no identifiable forams
34R-CC-012-014
Very poor preservation/ no identifiable forams
35R-01-000-003
Very poor preservation/ no identifiable forams
35R-01-050-052
Very poor preservation/no identifiable forams
35R-01-101-103
Moderate- poor preservation/algae spores/recrystallization
35R-02-000-003
Moderate- poor preservation
35R-02-050-053
Very poor preservation/small pocket of finer grained sediments/little to no identifiable features
35R-02-105-108
Very poor preservation/forams have been recrystallized
35R-03-000-002
Very poor preservation/forams have been recrystallized
35R-03-048-051
Very poor preservation/forams have been recrystallized

35R-03-100-103
Very poor preservation/forams have been recrystallized
35R-04-000-002
Poor preservation
35R-04-049-052
Very poor preservation/forams have been recrystallized
35R-04-100-102
Very poor preservation/ no identifiable forams
35R-05-000-003
Moderate-poor preservation/recrystallization of some forams/small turbiduty flows/
35R-05-049-052
Very poor preservation/no identifiable features/forams have been recrystallized
35R-05-101-103
Very poor-poor preservation/forams have been recrystallized
35R-06-000-003
Very poor preservation/little to no identifiable markers/forams have been recrystallized
35R-06-050-053
Very poor preservation/no identifiable forams
35R-06-100-102
Moderate-poor preservation/forams have been recrystallized
35R-CC-014-016
Poor preservation/forams have been recrystallized
36R-01-000-004

Very poor preservation/ little to no identifiable features/forams have been recrystallized/wavy pattern in thin section (cycles)
36R-01-049-052
Very poor preservation
36R-01-100-103
Very poor-poor preservation/fragments of fossils
36R-02-000-003
Very poor preservation/benthics present
36R-02-050-053
Very poor preservation/forams have been recrystallized
36R-02-101-104
Very poor preservation/forams have been recrystallized
36R-03-000-002
Very poor preservation/forams have been recrystallized
36R-03-052-055
Very poor preservation
36R-03-105-107
Poor preservation
36R-04-000-003
Poor preservation
36R-04-049-053
Poor preservation
36R-04-099-102

Very poor preservation/ forams have been recrystallized
36R-05-000-003
Very poor preservation/ forams have been recrystallized
36R-05-050-054
Very poor preservation/ forams have been recrystallized
36R-05-100-103
Very poor preservation/ forams have been recrystallized
36R-06-000-003
Poor preservation
36R-06-050-052
Moderate preservation
36R-CC-008-010
Moderate- poor preservation
37R-01-002-004
Very poor preservation/forams have been recrystallized
37R-01-049-052
Moderate- poor preservation
37R-01-097-102
Poor preservation
37R-02-000-003
Moderate- poor preservation
37R-02-050-053
Very poor preservation/forams have been recrystallized/ turbidity flow

37R-02-099-103
Poor preservation/turbidite flow?
37R-03-000-004
Very poor preservation/bottom of slide showed recrystallization of forams
37R-03-049-052
Very poor preservation/bottom of slide showed recrystallization of forams/little to no identifiable forams
37R-03-098-101
Very poor preservation/no identifiable forams
37R-04-000-004
Very poor preservation/small turbidity flow
37R-04-049-051
Very poor preservation
37R-04-100-103
Very poor preservation/bottom of slide showed recrystallization of forams/little to no identifiable forams
37R-05-000-003
Very poor preservation/ no identifiable forams
37R-05-051-054
Moderate- Poor preservation
37R-05-102-105
Very poor-poor preservation
37R-06-003-005

Very poor preservation/forams have been recrystallized
37R-CC-009-012
Poor preservation

Appendix C

Foraminifera List

Genus: *Acaranina*

Acarinina were a dominant component of the Eocene assemblages, mostly though the early to middle Eocene. Many of the species have been noted to have been mixed-layer dwellers with the carbon isotopic characteristics indicating a photo-symbiotic life. Included in this section are ten species.

Species: *Acaranina aspensis* (Colom, 1954)

Globigernina aspensis (Colom, 1954), *Globorotalia aspensis* (Bolli, 1957), *Acarinina aspensis* (Hillebrandt, 1956), *Turborotalia (? Acarinina) aspensis* (Samuel and Salaj, 1968), *Globorotalia (Acarinina) aspensis* (Blow, 1979), *Acarinina pentacamerata* (Subbotina *acceleratoria* Khalilov, 1956), *Globigerina colomi* (Bermüdez, 1961)

Biostratigraphic Range: lower E7

Geographic Distribution: Sub-tropical regions

Description: Normal perforate, non-spinose wall texture with coarse muricate. Test morphology: low trochosiral, subglobular chambers ranging from 6-8, rarely 10. Distinguishing features are its large and widely open umbilicus and high but variable number of subglobular chambers.

Species: *Acaranina bullbrooki* (Bolli, 1957)

Plate 1, Figures A-C

Globorotalia crossata (Cushman and Barksdale, 1930), *Globorotalia (Truncorotalia) crassata* (Cushman and Bermüdez, 1949), *Globorotalia densa* (Pessagno, 1960), *Acarinina densa* (Berggren, 1977), *?Globorotalia (Acarinina) decepta* (Blow, 1979), *?Globoigerina* *spinuunflata* (Bandy, 1949), *?Globorotalia (Acarinina) spinuloinflata* (Jenkins, 1971), *globorotalia crassaformis* (Subbontina, 1953), *Globorotalia bullbrooki* (Bolli, 1957b) *Globorotalia (Acarinina) bullbrooki,* (Blow, 1979), *Globorotalia (Acarinina)* sp. ex intere. *G (A.) pseudotopilensis* and *G. (A.) bullbrooki* (Blow, 1979), *Globorotalia (Acarinina)* cf. *bullbrooki* (Blow, 1979), *Acarinina bullbrooki* (Huber, 1991), *Globorortalia (Acarinina) matthewsae* (Blow, 1979), *Acarinina matthewsae* (Huber, 1991)

Biostratigraphic Range: E7-E11

Geographic Distribution: Cosmopolitan

Description: Strongly muricate, non-spinose wall texture with normal perforate. Test morphology: Quadrate, low-trochospiral with 4 inflated moderately embracing, hemispherical chambers in the last whorl. The umbilicus is narrow to moderately wide in some younger forms. Aperture is a low, rimmed opening extending towards the periphery. The distinguished features are its sub-quadrate test, closely appressed and embracing chambers, rounded to subangular periphery and weak to moderate murical concentration on the periphery.

Species: *Acarinina coalingensis* (Cushman and Hanna, 1927)

Plate 1, Slides D-F

See Olsson and other (1999) for synonymy lost and taxonomic discussion.

Biostratigraphic Range: P4c-E7

Geographic Distribution: Not given

Species: *Acarinina collactea* (Finlay, 1939)

Plate 2, Slides A-C

Globorotalia collactea (Finlay, 1939), *Globorotalia collactea* (Hornibrook 1961), *Truncorotaloides collactea* (Jenkins, 1965a), *Globorotalia (Acarinina) collactea* (Blow, 1979), *Acarinina collactea* (Stott and Kennett, 1990), *Truncorotaliodes collacteus* (Poore and Bybell, 1988), *Acarinina rotundimarginata* (Berggren, 1960), *Globorotalia spinuloinflata* (Bolli, 1957b), *Truncorotaloides pseudodubia* (Berggren 1969), Not *Globigerina collactea* (Brönnimann, 1952)

Biostratigraphic Range: E7-E14

Geographic Distribution: Cosmopolitan

Description: Normal perforate non-spinose wall texture with the walls being densely muricate on both sides. Test morphology: Low-trochospiral, 5 subangular, equal sized chambers in the last whorl. The umbilicus is narrow and deep with the aperture having a low, arched slit along the base of the last chamber. This species small size, 5 chamber compact test is its distinguishing feature.

Species: *Acarinina cuneicamerata* (Blow, 1979)

Plate 2, Slides D-F

? Globorotalia berwaliana (Mohan and Soodan, 1969), *Globorotalia (Acarinina) cuneicamerata* (Blow, 1979), *Globorotalia (Acarinina)* sp. ex interc. *G. (A.). decepta* and *G. (A.) cuneicamerata* n.sp. (Blow, 1979)

Biostratigraphic Range: E6-E9

Geographic Distribution: Equatorial Atlantic Ocean, Tethyan region and Indian Ocean.

Description: Normal perforate, non-spinose wall texture with the walls being densely muricate.

Test morphology: Low trochospiral, 5-6 moderately inflated, strongly muricate chambers in the last whorl. Umbilicus is wide and deep with relict aperture of ante- and penultimate chambers visible within the umbilical area.

Species: *Acarinina pentacamerata* (Subbonina, 1947)

Plate3, Slides A-C

Globorotalia crassa d'Orbigny *pentacamerata* (Subbotina, 1936), *Globorotalia pentacamerata* (Subbotina, 1947), *Acarinina pentacamerata* (Subbontina, 1953), *Turborotalia (Acarinina) pentacamerata* (Pokorny, 1960), *Globorotalia (Arcarinina) pentacamerata* (Hillebrandt, 1962), *Acarinina pentacamerata* (Subbotina) var. *camerata* (Blow, 1979), *Globorotalia (Acarinina) camerata* (Blow, 1979), *Globirgerina soldadoensis* Brönnimann-*Globigerina gravelli* Brönnimann transitional form. (Brolli, 1957a), *Globirgerina mckannai* (Berggren, 1960a)

Biostratigraphic Range: E5-E7

Geographic Distribution: Global distribution in the early Eocene

Description: Densely muricate on both sides with a normal perforate, non-spinose wall texture.

Test morphology: Low-trochospiral usually 5 rounded, inflated chambers increasing gradually in size in the last whorl. The umbilicus is generally small, deep with concentration of muricae around the circum-umbilical region.

Species: *Acarinina praetopilensis* (Blow, 1979)

Plate 3, Slides D-F

Globorotalia (truncorotaloides) topilensis praetopilensis (Blow, 1979), *Acarinina praetopilensis* (Berson et al., 2004), Not *Acarinina praetopilensis* (Wade et al., 2001)

Biostratigraphic Range: Upper E7-E12

Geographic Distribution: Widespread distribution in Tethyan and South Atlantic regions.

Description: strongly muricate with normal perforate and non-spinose wall texture. Test morphology: Low-trochospiral, sutures radial, straight, depressed between overlapping junctions of juxtaposed inflated chambers. The umbilicus is deep and wide with no circum-umbilical muricate rim/collar.

Species: *Acarinina primitiva* (Finlay, 1947)

Plate 4, Slides A-C

Globoquadrina primitiva (Finlay, 1947), *Globigerina primitiva* (Brönniman, 1952), *Pseudogloboquadrina primitiva* (Jenkins, 1965b), *Globorotalia (Acarinania) primitiva* (Blow, 1979), *Acarinina primitiva* (Stott and Kennett, 1990), Not *Globigerina primitiva* (Bolli, 1957), Not *Globorotalia (Acarinina) primitiva* (Hillebrandt, 1962)

Biostratigraphic Range: E6-E13

Geographic Distribution: Temperate-high latitude

Description: Coarsely muricate and non-spinose with normal perforate wall texture. Test morphology: Robust, compact and subquadrate test with 3-4 triangular-shaped chambers in the last whorl. The chambers are arranged at right angles to each other and are separated by sutures in the umbilicus side. The umbilicus is narrow and deep with the aperture being asymmetrically placed at the base of the last chamber. The triangular chambers and the asymmetrically situated aperture are the distinguishing features of this species.

Species: *Acarinina pseudotopilensis* (Subbotina, 1953)

Acarinina pseudotopilensis (Subbotina, 1953), *Globorotalia pseudotopilensis* (Reyment, 1960), *Globorotalia (Acarinina) pseudotopilensis* (Hillebrandt, 1962), *Turborotaila pseudotopilensis* (Gorhbandt, 1963), *Truncorotaloides psuedotopilensis* (Jenkins, 1971), *Turborotalia (Acarinina) psuedotopilensis* (Samuel et al., 1972), *?Acarinina pseudotopilensis* (Lu and Keller, 1995), Not *Acarinina pseudotopilensis* (Pearson et al., 1993)

Biostratigraphic Range: P5 or E1- lower E7

Geographic Distribution: Widely distributed in sub-tropical regions

Description: Densely muricate and non-spinose with normal perforate wall texture. Test morphology: Subquadrate to suboval with a weakly lobulated outline. Four inflated chambers in the last whorl with the umbilicus sutures having depressed or incised. The umbilicus is small and deep and in most specimen obscured by overhanging, round umbilical shoulder.

Species: *Acarinina quetra* (Bolli, 1957)

Plate 4, Slides D-F

Globorotalia quetra (Bolli, 1957), *Globorotaila (Acarinina) quetra* (Hillebrandt, 1962), *Acarinina quetra* (Fleisher, 1974), *Globorotalia (Truncorotaloides) quetra* (Blow, 1979), *Morozovella quetra* (Snyder and Waters, 1985)

Biostratigraphic Range: E3-E6

Geographic Distribution: Widely distributed in sub-tropical regions

Description: Moderately to strongly muricate with concentration of muricate along the peripheral margin of last whorl and non-spinose with normal perforate wall texture. Test morphology: Low trochospiral; test is subquadrate and planoconvex. There are 4 broadly subtriangular chambers that are visible in the umbilicus view. Umbilicus is wide and deep while the aperture is umbilical-extraumbilical, arch extending towards the peripheral margin.

Genus: *Astrorotalia*

The monospecific genus *Astrorotalia* lived a very short range in E7 before becoming extinct. This genus is defined by its peripheral keel that extends into blade-like projections at the midpoint of each chamber in the last whorl.

Species: *Astrorotalia palmerae* (Cushman and Bermùdez, 1937)

Plate 5, Slides A & B

Globorotalia palmerae (Cushman and Bermùdez, 1937), *Pararotalia? palmerae* (Cushman and Bermùdez, 1949), *Globorotalia (Panorotalites) palmerae* (Hillebrandt, 1976), *Globorotalia (Planorotalites)* cf. *palmerae* (Hillebrandt, 1976), *Planorotalites palmerae* (Berggren, 1977), *Globorotalia (Astrorotalia) stellaria* (Turnovsky, 1958)

Biostratigraphic Range: Lower part of E7-E9?

Geographic Distribution: Restricted to tropical regions

Description: non-spinose with weakly muricate and normal/ coarsely perforate wall texture. Test morphology: Low trochospiral test with peripheral keel that extends into blade-like. There are tapering keel-spines on each chamber. There are 5-7 moderately inflated, triangular-shaped chambers in the last whorl. The umbilicus is narrow and shallow with the aperture having a low umbilical-extraumbilical slit bordered by a thick lip extending into the periphery.

Genus: *Globigerinatheka*

The genus *Globigerinatheka* colonized surface water habitats across a wide range of latitudes. All of this genus possess a cancellate wall with ridges that are arranged in polygons with some species indicate that they were densely spinose life.

Species: *Globigerinatheka kugleri* (Bolli, Loeblich and Tappan, 1957)

Plate 5, Slides C

Globigerinatheka barri (Brönnimann, 1952), *Globigerinatheka mexicana barri* (Bolli, 1972), *Globigerapsis kugleri* (Bolli, Loeblich and Tappan, 1957), *Globigerinatheka kugleri* (Proto Decima and Bolli, 1970), *Globigerinatheka mexicana kugleri* (Bolli, 1972), *Globigerapsis kugleri kugleri* (Blow, 1979), *?Globigerinatheka kugleri* (Pujol, 1983), *Globigerinatheka mexicana* (Mallory, 1959), *Globigerinatheka mexicana mexicana* (Bolli, 1972), *?Globigerinatheka mexicana* (Stainforth et al., 1975), *Porticlashparea mexicana mexicana,* (Blow, 1979), *Globigerapsis index* (Blow and Banner, 1962), *Porticulasphaera mexicana howei* (Blow 1979), *Globigerinatheka subconglobata subconglobata* (Toumarkine, 1983), Not *Globigerapsis kugleri* (Bolli, 1957)

Biostratigraphic Range: E9-E13

Geographic Distribution: Tropical to temperate regions.

Description: Spinose and cancellate with pores wall texture. Test morphology: The test is subtriangular in the outline and somewhat lobate. There is 2-3 whorls with the first coil being very tight and composed of an unknown amount of very small chambers that are globular in shape. The second coil is looser with four globular chambers that increase gradually in size. The last coil has four very rapidly enlarging globular chambers.

Species: *Globigerinatheka mexicana* (Cushman, 1925)

Plate 5, Slide D

Globigerina mexicana (Cushman, 1925), *Globigerapsis mexicana* (Saito, 1962), *Globigerinatheka mexicana mexicana* (Bolli, 1972), *?Globigerinatheka mexixcana mexicana* (Fleisher, 1974), *Globigerinatheka mexicana* (Stainforth et al., 1975), *Porticulasphaera mexicana mexicana* (Blow, 1979), *?Globigerinatheka mexicana* (Pujol, 1983), *Globigerinatheka kutchensis* (Singh and Tewari, 1967), *?Globigerinatheka ?* sp. (cf. *Globigerinatheka barri* Brönnimann) (Samuel and Salaj, 1968), *Globigerinatheka barri* (Samanta, 1970), *Globigerapsis tropicalis* (Blow, 1969), *Globigerinoides kugleri* (Mohan and Soodan, 1970), *?Globigerinatheka index* (Berggren, 1992), Not *Globigerina mexicana* (Cushman, 1927), Not *Globigerinoides mexicana* (Beckman, 1953), Not *Portculasphaera mexicana* (Bolli, Loeblich, and Tappan, 1957), Not *Globigerinatheka mexicana mexicana* (Toumarkine, 1978), Not *Globigerapsis mexicana* (Blow, 1979)

Biostratigraphic Range: E9-E14

Geographic Distribution: Low to mid latitudes.

Description: Spinose, cancellate, and densely porous wall texture. Test morphology: The test is nearly spherical with the earlier chambers arranged in a low trochospire consisting of at least six subglobular chambers. The last chamber is large and inflated which comprises of half of the entire test.

Species: *Globigerniatheka subconglobata* (Shutshaya, 1958)

Plate 5, Slides E & F

Globigerapsis index (Bolli, 1957), *Globigerinatheka index index* (Bolli, 1972), *Globigerinatheka index* (Stainforth and others, 1975), *Globigerinoides subconglobatus* (Shutskaya, 1958), *Globigerapsis subconglobatus* (Toumarkine, 1971), *Globigerinatheka subconglobata subconglobata* (Bolli, 1972), *?Globigerinatheka subconglobata subconglobata* (Fleisher, 1974), *Globigerinatheka subconglobata* (Stainforth et al., 1975), *?Globigerinatheka subconglobata* (Snyder and Waters, 1985), *Globigerinatheka mexicana mexicana* (Toumarkine, 1978), Not *Globigerinatheka subconglobata subconglobata* (Toumarkine, 1975)

Biostratigraphic Range: E8-E13

Geographic Distribution: Cosmopolitan common.

Description: Spinose, cancellate, with thick pores in wall texture. This species is frequently recrystallized. Test morphology: The test ranges from globular to nearly spherical formed by three whorls that is initially coiled in low trochospire that is becoming progressively higher and slightly streptospiral in the last whorl.

Genus: *Globoturborotalita*

Globoturborotalita first appeared in the middle Eocene and continued to exist up into the Oligocene. This genus is a member of the family Globigernidae and is characterized by an umbilical aperture with a lip of consistent thickness and a coarse cancellate wall texture.

Species: *Globoturborotalita bassriverensis* n. sp. (Olsson and Hemleben)

Plate 6, Slides A & B

Biostratigraphic Range: E1-E10?

Geographic Distribution: Distributed to mid- and low latitudes.

Description: Cancellate, non-spinose, and normal perforate with sacculifer-type wall texture.

Test morphology: Moderately low trochospiral; chambers are globular, spiral view showing 4 globular slightly embracing chambers in the ultimate whorl. The umbilicus is small, open, and enclosed by surrounding chambers. The aperture is umbilical and has a rounded arch. This species is distinguished by its small size, 4 globular and slightly embracing chambers in the last whorl.

Genus: *Guembelitriodes*

The genus *Guembelitriodes* is defined by its presence of supplementary sutural apertures and closely resembles the modern genus *Globigerinoides.* This genus is described to have a sacculifer type wall texture and a globigerini-form. *Guembelitriodes* is separated from the high-spired *Subbotina gortanii* group by its presence of supplementary sutural apertures in most of the specimens.

Species: *Guembelitriodes nuttallli* (Hamilton, 1953)

Plate 6, Slides C & D

Globigerinoides nuttalli (Hamilton, 1953), *Guembelitrioides nuttalli* (Pearson et al., 2004), *"Globigerinoides" higgensi* (Bolli, 1957b), *Globirgerinoidesw higginsi* (Samanta, 1970), *Globigerina higginsi* (Stainforth and others, 1975), *Globigerinoides? higginsi* (Blow, 1979), *Guembelitrioides higginsi* (Pearson et al, 1993), Not *Globigerina higginsi* (Pujol, 1983), Not *Subbotina higginsi* (Nocchi et al., 1992), Not *Globigerina higginsi* (Warraich and Ogasawara, 2001)

Biostratigraphic Range: Base of E8- top of E10.

Geographic Distribution: Mid to low-latitudes.

Description: Cancellate and spinose with a sacculifer-type wall texture. Test morphology: The test is trochospiral and starts off as moderately high spired to helicospirl late in ontogeny. The chambers are globigerini-form, meaning that there are spherical and they increase in size as added. The last chamber is often ovate with 9-10 chambers arranged in 2 ½-3 loosely coiled whorls. The umbilicus is narrow and deep and sometimes covered by a bulla of different sizes.

Genus: *Hantkenina*

Hantkenina is classified as one of the most widespread and long-ranging genus in the family, Hantkeninidae. During the middle and late Eocene, this genus underwent a drastic morphological evolution that involved the position and orientation of the tubulospines.

Species: *Hantkenina liebusi* (Shokhina, 1937)

Plate 6, Slide E

Siderolina kochi (Hantken, 1875), *Pullenia kochi* (Liebus, 1911), *Hantkenina kochi (*Cushman, 1924), *?Hantkenina longispina* (Cushman, 1924), *Hantkenina liebusi* (Shokhina, 1937), *Hantkenina (Applinella) liebusi*, (Thalmann, 1942), *Hantkenina (Aragonella) liebusi,* (Ramsay, 1962), *Hantkenina* cf. *liebusi,* (Raju, 1968), *Hantkenina (Aragonella)* aff. *mexicana* (Brönnimann, 1950), *Hantkenina (Applinella) trinitatensis,* (Brönnimann, 1950)

Biostratigraphic Range: Mid E8 to basal Zone E13.

Geographic Distribution: Worldwide distribution in the low to mid latitudes but absent in high southern and northern latitudes.

Description: Smooth, normal performate and more than likely nonspinose wall texture. Test morphology: The test is planispiral, involute, and biumbilicate. There are 4-6 subtriangular chambers in the adult whorl and is laterally compressed. The chambers increase in size as they are added. Each of the chambers in the last whorl extends into a hollow tubulospine. The aperture is narrow with an elongated equatorial arch bordered by an imperforate lip.

Genus: *Igorina*

The genus *Igorina* is discussed in further detail in the Atlas of Paleocene Planktonic Foraminifera (Olsson et. al., 1999).

Species: *Igorina broedermanni* (Cushman and Bermùdez, 1949)

Plate 6, Figure F

Globorotalia (Truncorotalia) broedermanni (Cushman and Bermùdez, 1949), *Globorotalia broedermanni* (Bolli, 1957a), *Pseudogloborotalia broedermanni* (Bermùdez, 1961), *Globorotalia (Acarinina) broedermanni broedermanni* (Blow, 1979), *Acarinina* *broedermanni* (Snyder and Waters, 1985), *'Morozovella' broedermanni* (Pearson et al., 1993), *Igorina broedermanni* (Lu and Keller, 1995), *Globorotalia mattseensis* (Gohrbandt, 1967), *Globorotalia wartsteinensis* (Gohrbandt, 1967), *Acarinina planodorsalis* (Fleisher, 1974)

Biostratigraphic Range: E1 to top of E9.

Geographic Distribution: Widespread in the Caribbean, Atlantic, and Indo-Pacific realms.

Description: Muricate and nonspinose with normal perforate. Test morphology: The test is subcircular and weakly lobulated. The test is also low trochospiral with blunt-tipped muricae covering both sides of the test. There are 6-7 equidimensional, triangular-shaped chambers. The umbilicus is narrow and deep. The aperture is a low slit extending towards the peripheral margin.

Genus: *Morozovella*

The genus *Morozovella* is distinguished from other genera by the muricate, angloconical test and peripheral muricocarina (most of the species) of variable breadth and strength. *Morozovella* has a stratigraphic range of the mid-Paleocene to middle Eocene.

Species: *Morozovella aragonesis* (Nuttall, 1930)

Plate 7, Slides A & B

Globorotalia aragonensis (Nuttall, 1930), *Globorotalia (Truncorotalia) aragonensis* (Cushman, and Bermùdez, 1949), *Pseudogloborotalia aragonensis* (Bermùdez, 1961), *Morozovella aragonensis aragonensis* (Fleisher, 1974), *Morozovella aragonensis* (Berggren, 1977), *Globorotalia (Morozovella) aragonensis* (Blow, 1979), *Globorotalia marksi* (Martin, 1943), *Globorotalia naussi* (Martin, 1943)

Biostratigraphic Range: Base of E5-top of E9.

Geographic Distribution: Widely distributed in sub-tropical-Tethyan regions and common in the Caribbean, Mediterranean-Pyrenees, and North Causcasus Indo-Pacific.

Description: Muricate and non-spinose with normal perforate wall texture. Test morphology: The test periphery is nearly circular, weakly lobulated and planoconvex. There are 5-7 chambers in the last whorl with triangular and inflated chambers on the umbilical side and trapezoidal to lozenge shaped on spiral side. The umbilicus is narrow, deep, and rimmed by rounded tips at the circum-umbilical chamber.

Species: *Morozovella caucasica* (Glaessner, 1937)

Plate 7, Slides C & D

Globorotalia aragonensis Nuttall var. *caucasia* (Glaessner, 1937), *Truncorotalia caucasica* (Reiss, 1957), *Truncorotalia (Truncorotalia)* cf. *caucasica* (von Hillebrandt, 1962), *Globorotalia caucasica* (Luterbacher, 1964), *Globorotalia (Morozovella) crater caucasica* (Jenkins, 1971), *Morozovella aragonensis caucasica* (Blow, 1979), *Morozovella caucasica* (Toumarkine and Luterbacher, 1985), *Globorotalia velascoensis* (Subbontina, 1953)

Biostratigraphic Range: Zone E6-E8.

Geographic Distribution: Widely distributed in sub-tropical-Tethyan regions and common in the Aquitaine Basin and the Indo-Pacific region.

Description: Muricate and non-spinose with normal performate wall texture. Test morphology: The test is sub-circular, moderately lobulate peripheral outline, and planoconvex. The chambers are triangular on the umbilicus side and trapezoidal to sub-quadrate on the spiral side as a function of degree of the curvature of the intercameral sutures. In spiral view, there are 15-18 chambers in three whorls with the early chambers slightly raised about the test surface.

Species: *Morozovella crater* (Hornibrook, 1958)

Plate 7, Slides E & F

Globorotalia crater (Finlay, 1939a), *Globorotalia (Morozovella) crater* (Jenkins, 1971), *Morozovella crater* (Pearson et al., 2004), *Globorotalia aragonensis* Nuttall var. *twisselmanni* (Mallory, 1959), *Globorotalia (Morozovella) gorrondatxensis* (Orue-Etzebarria, 1958), Not *Globorotalia crater* (Finlay, 1939b)

Biostratigraphic Range: Zone E4-E9.

Geographic Distribution: Widely distributed in sub-tropical areas of Atlantic, Mediterranean/Tethyan, Pacific Oceans and austral regions.

Description: Muricate and non-spinose with normal perforate wall textures. Test morphology: The test is planoconvex with lobulated outline and 4 ½ -5 essentially equidimensional chambers in that last whorl. The umbilicus is deep and wide, rimmed by everted, thickened circumumbilical rim of elevated chamber shoulders. The distinguishing features of this species is the 4 ½- 5 essentially equidimensional chambers in the last whorl, thickened circumumbilical rim of the elevated chamber shoulders, and strongly limbate sutures on spiral side.

Species: *Morozovella formosa* (Bolli, 1957b)

Plate 8, Slides A & B

?Globorotalia velascoensis (Cushman and Renz, 1946), *Globorotalia formosa formosa* (Bolli, 1957b), *Pseuodogloborotalia formosa* (Bermùdez, 1961), *Globorotalia formosa* (Postuma, 1971), *Morozovella formosa* (Berggren, 1971), *Globorotalia (Morozovella) formosa* (Blow, 1979), *Morozovella formosa Formosa* (Warraich et al., 2000)

Biostratigraphic Range: Base of E4-top of E6.

Geographic Distribution: Widely distributed in sub-tropical regions.

Description: Muricate and non-spinose with normal perforate wall texture. Test morphology: The test is sub-circular, moderately lobulate peripheral outline, and planoconvex. The chambers are triangular. Inflated and sub-angular on the umbilicus side and trapezoidal with curved margins on the spiral side of the chambers. The umbilicus is open, moderately wide and deep with the main aperture a low umbilical-extraumbilical arch extending to the peripheral margin.

Species: *Morozovella subbotinae* (Morozova, 1939)

Plate 8, Slides C & D

Globorotalia subbotinae (Morozova, 1939), *Globorotalia (Morozovella) subbotinae subbotinae* (Blow, 1979), *Globorotalia crassata* (Subbotina, 1947), *Morozovella subbotinae* (Berggren, 1971), *Globorotalia rex* (Martin, 1943), *Truncorotalia* cf. *rex* (Gohrbandt, 1963), *Globorotalia (Morozovella) aequa rex* (Jenkins, 1971), *Globorotalia bollii* (El Nagger, 1966), *Globorotalia nartanensis* (Shutshaya, 1970b), *Globorotalia (Truncorotalia) aequa simulatilis* (Hillabrandt, 1962), Not *Globorotalia rex* (Loeblich and Tappan, 1957)

Biostratigraphic Range: P5-E5

Geographic Distribution: Widely distributed in sub-tropical regions in Atlantic, Indo-Pacific, and typical Tethyan biogeographies and as far south as 60˚S.

Description: Normal perforate and non-spinose with a muricate wall texture. Test morphology: The test is mostly large and planoconvex to weakly biconvex. The test is also moderately lobulated, strongly keeled periphery. There are 4 to 4 ½ chambers in the last whorl. The umbilicus is deep and narrow with the aperture being distinguished by a low, umbilical-extraumbilical slit extending almost to the periphery and is bordered by a weak lip.

Genus: *Parasubbotina*

Parasubbontina are characterized by a cancellate spinose wall texture.

Species: *Parasubbontina eoclava* (Coxall, Huber, and Pearson, 2003)

Plate 8, Slides E &F

Subbotina inaequispira (Blow, 1979), *Clavigerinella ?columbiana* (McKeel and Lipps, 1975), *Parasubbotina eoclava* (Coxall, Huber, and Pearson, 2003)

Biostratigraphic Range: E7-E9.

Geographic Distribution: Low to mid-latitudes.

Description: Reticulate *Clavigerinalla*-type wall texture and is spinose in life. Test morphology: The test is characterized by its very low trochospiral, somewhat laterally compressed, lobulated-petaloid in outline. The test chambers are globular and well separated with the last chamber to become slightly radially elongated. The umbilicus is moderately small, narrow and deep.

Genus: *Problematica*

Problematica is an enigmatic taxon. There appears to be no ancestral linkage for this genus when it first appeared in the lower Eocene. This genus is tentative until future studies are able to establish its phylogeny.

Species: *Praemurica? Lozanoi* (Colom, 1954)

Plate 9, Slides A & B

?Globigerina prolata (Bolli, 1957a), *Globigerina lozanoi prolata* (Blow, 1979), *Globigerina prolata* (Warraich and Ogasawara, 2001), *Globigerina lozanoi* (Colom, 1954), *Globigerina (Eoglobigerina) lozanoi* (Hillebrandt, 1976), *Globigerina lozanoi lozanoi* (Blow, 1979), *Subbotina lozanoi* (Nocchi et al., 1991), Not *Globigerina lozanoi* (Stott and Kennett, 1990), Not *Subbotina lozanoi* (Nocchi et al., 1991)

Biostratigraphic Range: E6-E10

Geographic Distribution: Cosmopolitan, more common in mid to low latitudes.

Description: Smooth, non-spinose, and cancellate wall texture. Test morphology: The test is trochospiral and asymmetrically biconvex. The first two whorls of this species are coiled in a medium high, tight spire then the coiling modes tends to become more evaluate. The chambers are globular and increase in size as added with the 5-6 chambers added in the last whorl. The umbilicus is medium-sized and deep while the aperture is a distinct, moderately high arch.

Genus: *Pseudoglobigerinella*

The *Pseudoglobigerinella* is noted to have *Clavigerinalle*-type wall structure.

Species: *Pseudoglobigerinella boliveriana* (Petters, 1945)

?Globigerina wilsoni (Stainforth, 1948), *Globigerina wilsoni bolivariana* (Petters, 1954), *Hastigerina? bolivariana* (Blow1979), *'Hastigerina' bolivariana* (Toumarkine and Luterbacher, 1985), *Globigerinella alexi* (Haque, 1956), *Globigerina? bolivariana* Petters subsp. *Pannonica* (Samuel, 1972), *Pseudohastigerina globulosa* (Hillebrandt, 1976), *Pseudohastigerina shpaeroidalies* (Hillebrandt, 1978)

Biostratigraphic Range: E7-E10.

Geographic Distribution: Only identified in middle Eocene low latitude upwelling areas.

Description: Normal perforate, spinose with high porosity and reticulate. *Clavigerinella*-type of wall structure that is covered by a thick crust in the adult stage of life. Test morphology: The test is globular with the test becoming asymmetrically planispiral in the adult stage whereas during the juvenile state the test is very low trochospiral. In spiral view, there four globular chambers that are embracing in the last whorl. In umbilical view, the chambers are also embracing but are increasing rapidly in size with the last chamber being inflated. The umbilicus is small and often times is covered by the last chamber.

Genus: *Subbontina*

The genus *Subbotina* was originally classified as *Globigerina* but they differ in having a sacculifer or sacculifer/ruber-type wall. Some of the Eocene species extensive, heavy gametopgenic calcification has been observed. This observation may reflect a greater range of adaption to the water column during the Eocene but the isotope data indicates that most of the *Subbontina* were thermocline dwelling forms.

Species: *Subbontina corpulenta* Subbotina, 1953)

Plate 9, Slides C & D

?*Globorotalia bulloides* d'Orbingy var. *cryptomphala* (Glaessner, 1937), *Globorotalia cryptomphala* (Toumarkine, 1957), *Globorotalia corpulenta* (Subbotina, 1953), *Globigerina pseudoeocaena* Subbotina var. *pseudoeocaena* (Subbotina, 1953), *Globigerina inflata* (Subbotina, 1953), ?*Globigerina protoreticulata* (Hofker, 1956), *Globigerina pera* (Todd, 1957), *Globigerinita pera* (Blow et al., 1962), *Catapsydrax pera* (Charollais et al., 1980), *Globigerina eocaena* (Poore and Brabb, 1977)

Biostratigraphic Range: E7-O1?

Geographic Distribution: Global in low to mid-latitudes.

Description: Spinose and cancellate with normal perforate wall texture. Test morphology: The test is moderately high trochospiral and lobulate in outline. The chambers are globular with 4-4½ in spiral view. The chambers increase in size with the umbilicus being moderate in size.

Species: *Subbontina crociapertura* (Blow, 1979)

Plate 9, Slides E & F

Subbotina crociapertura (Blow, 1979)

Biostratigraphic Range: E7-E12.

Geographic Distribution: Found in low latitudes.

Description: Spinose, cancellate, and normal perforate with *bulloides*-type wall texture. Test morphology: The test is low trochospiral and oval in outline and the globular outline in spiral view. The chambers are usually slightly embracing in the last whorl. The umbilicus is small, open, and is enclosed by the surrounding chambers.

Species: *Subbontina eocaena* (Guembel, 1868)

Plate 10, Slides A-C

Globigerina eocaena (Guembel, 1868), *Globigerina (Subbotina) eocaena* (Hagn and Lindenberg, 1969), ?*Globigerina eocaenica* (Terquem, 1882), *Globigerina eocaenica* Terquem var. *eocaenica* (Subbotina, 1953), *Subbotina eocaenica?* (Blow, 1979), *Globigerina bakeri* (Cole, 1927), *Globigerina eocaenica* Terquem var. *irregularis* (Subbotina, 1953), *Globigerina pseudoeocaena* Subbotina var. *pseudoeocaena* (Subbotina, 1953), *Globigerina pseudoeocaena* Subbotina var. *compacta* (Subbotina, 1953), *Globigerina pseudoeocaena* Subbotina var. *trilobata* (Subbotina, 1953), *Globigerina bulloides* Subbotina var. *compacta* (Subbotina, 1953), *Globigerina subtriloculinoides* (Khalilov, 1956)

Biostratigraphic Range: E6?-O1.

Geographic Distribution: global in low to mid-latitudes.

Description: Spinose, cancellate, and normal perforate with *ruber/sacculifer*-type wall texture. Test morphology: The test is low trochospiral. This species is oval in outline and chambers globular in spiral view. There are 3-4½ globular embracing chambers in the last whorl and increasing in size. The umbilicus is small and in enclosed by the surrounding chambers.

Genus: *Turborotalita*

Turborotalita exhibits the smooth-walled globorotaliform species that are some of the distinctive components of the upper Eocene planktonic foraminiferal assemblages. This genus has the tendency to defoliate in dissolved or recrystallized.

Species: *Turborotalita frontosa* (Subbotina, 1953)

Plate 10, Slides D-F

Globigerina frontosa (Subbotina, 1953), *Globorotalia cerroazulensis frontosa* (Toumarkine and Bolli, 1970), *Subbotina frontosa frontosa* (Blow, 1979), *Turborotalia cerroazulensis frontosa* (Toumarkine and Luterbacker, 1985), *Turborotalia frontosa* (Poore and Bybell, 1988), *Subbotina frontosa* (Pearson et al., 1993), *Globigerina boweri* (Bolli, 1957c), *Globigerina (Globigerina) boweri* (Jenkins, 1971), *Subbotina frontosa boweri* (Blow, 1979), *Globigerina ayalai* (Bermùdez, 1961), *Subbotina frontosa ayalai* (Blow, 1979), Not *Globigerina frontosa* (Krasheninnikov and Basov, 1983)

Biostratigraphic Range: E7-E11.

Geographic Distribution: Cosmopolitan.

Description: Weakly cancellate with raised cylindrical pustules on the beginning chambers with the later chambers smoother. This species also tends to defoliate. Test morphology: The test is trochospiral with the chambers being inflated, radially compressed, and increasing in size and the last chamber making up around half of the test. In the early chambers, the shape is considered globorotaliform and in the last whorl the shape is globigeriniform.

Species: *Turborotalita possagnoensis* (Toumarkine and Bolli, 1970)

Globigerina frontosa (Subbotina, 1953), *Globorotalia cerroazulensis possagnensis* (Toumarkine and Luterbacher, 1985), *Globorotalia cerroazulensis possagnensis* (Toumarkine and Bolli, 1970), *Turborotalia possagnoensis* (Poag and Commeau, 1995), Not *Turborotalia possagneosnsis* (Poore and Bybell, 1998)

Biostratigraphic Range: E9-E11.

Geographic Distribution: Cosmopolitan.

Description: Weakly cancellate with raised cylindrical pustules on the beginning chambers with the later chambers smoother. This species also tends to defoliate. Test morphology: The test is trochospiral and compressed with 3 chambers in the last whorl. The chambers are inflated and strongly radially compressed and appressed with increasing sizes.

APPENDIX D

Systematic Paleontology Plates of ODP #998, Cayman Rise

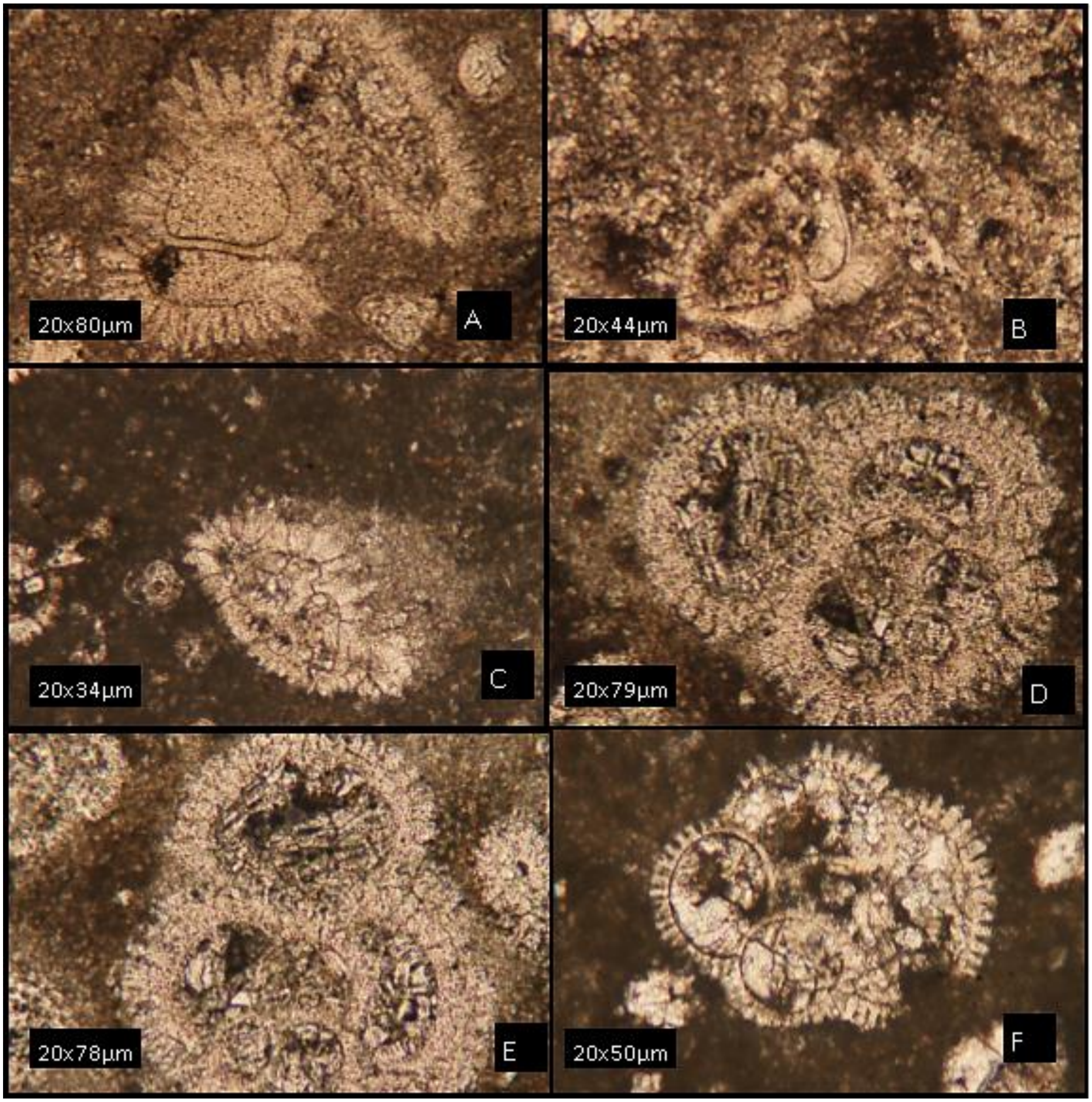


Plate 1:

Acaranina bullbrooki (Slides A-C), ***Acaranina coalengnesis*** (Slides D-F)

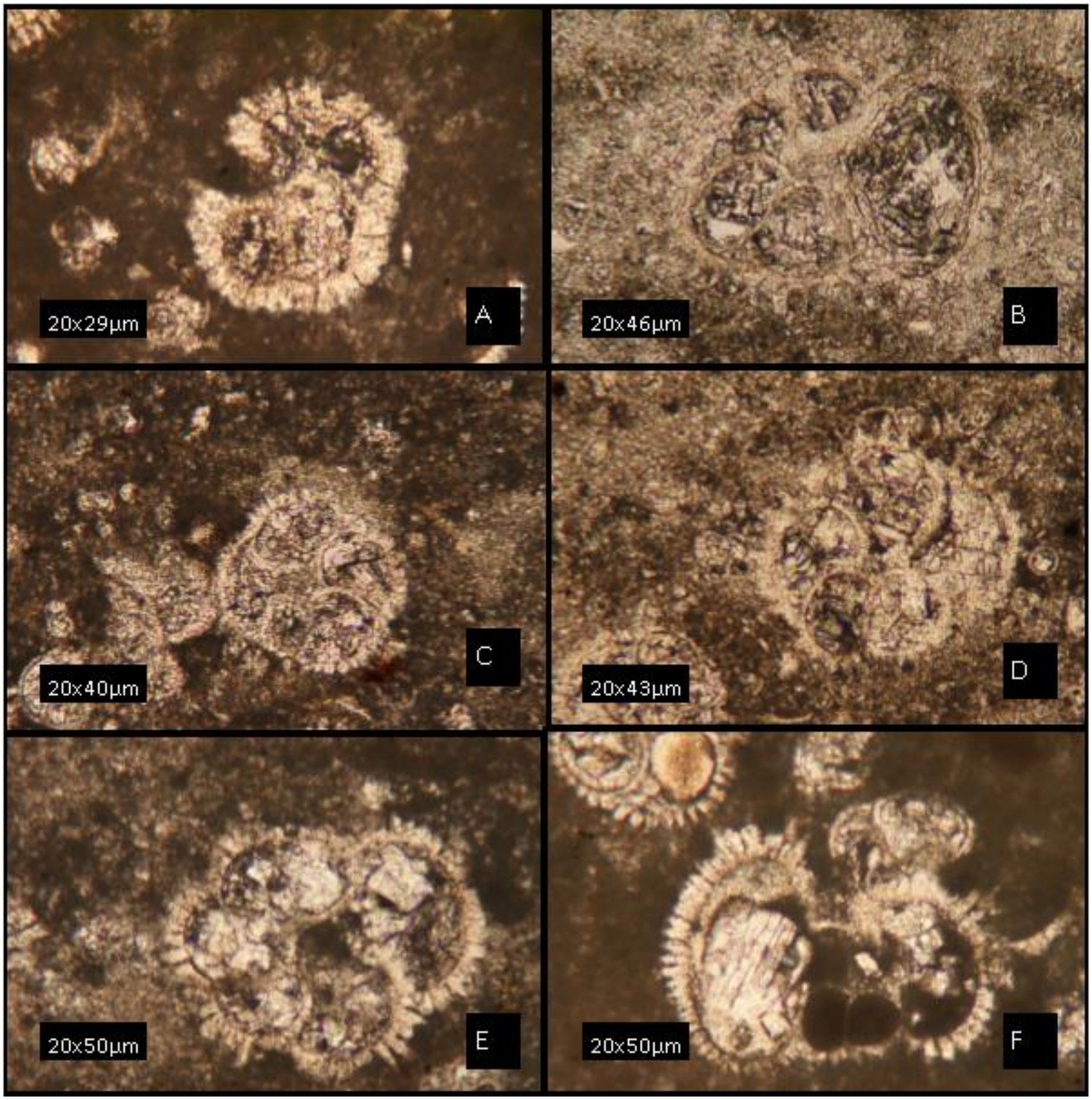


Plate 2:

Acarinina collactea (Slides A-C), ***Acarinina cuneicanerata*** (Slides D-F)

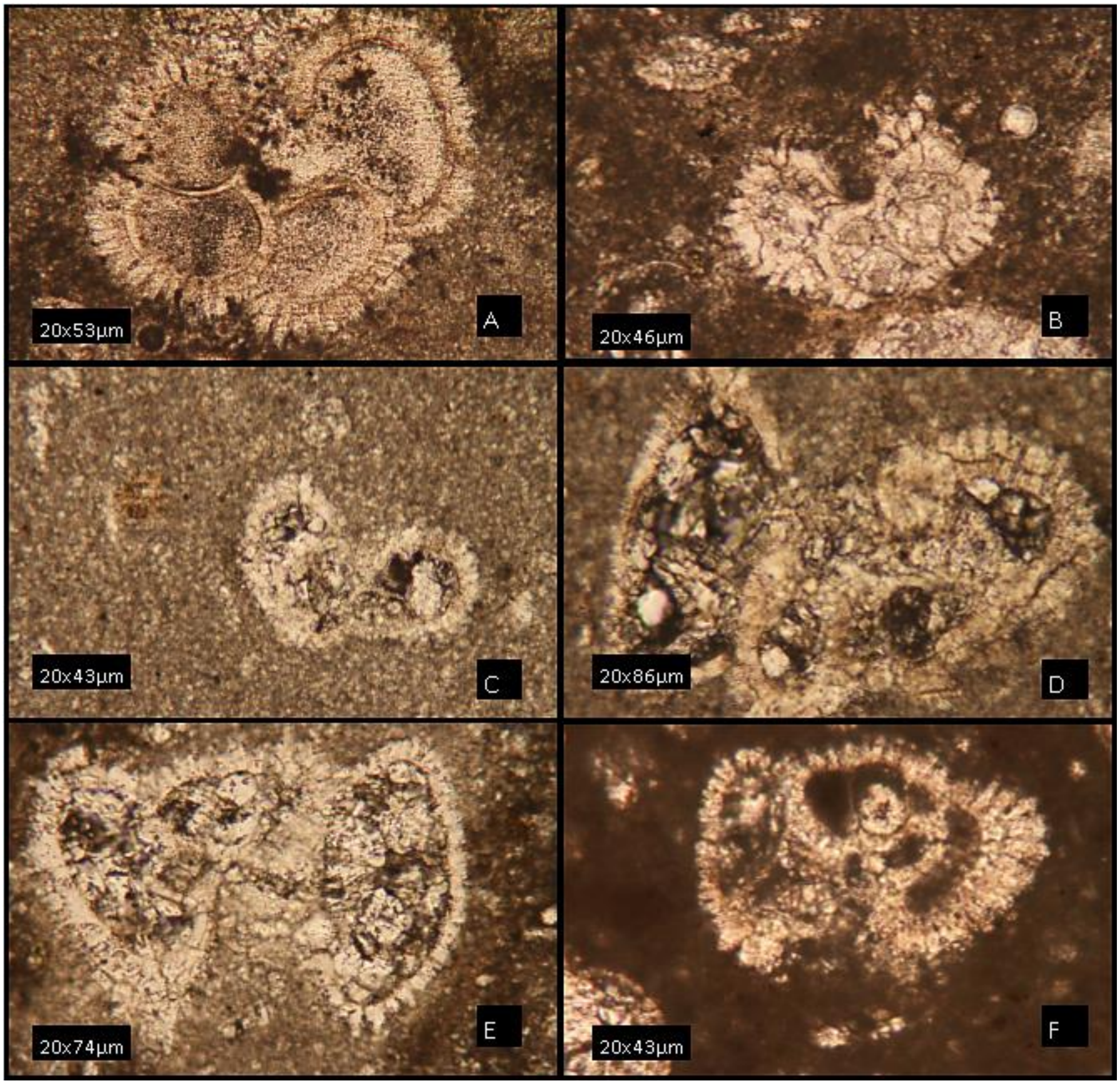


Plate 3:

Acaranina pentacamerata (Slides A-C), ***Acaranina praetopilensis*** (Slides D-F)

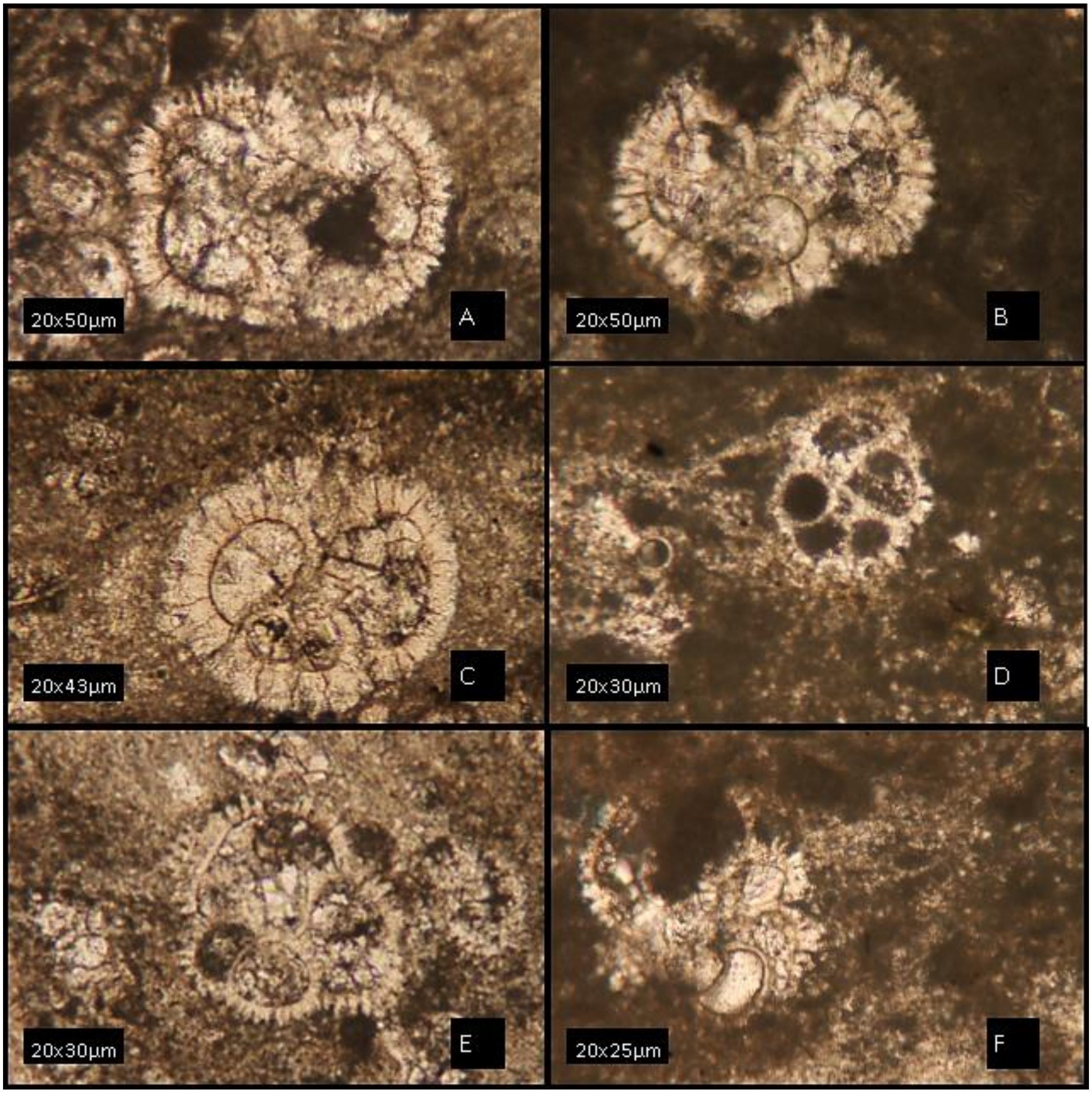


Plate 4:

Acaranina primitiva (Slides A-C), ***Acaranina quetra*** (Slides D-F)

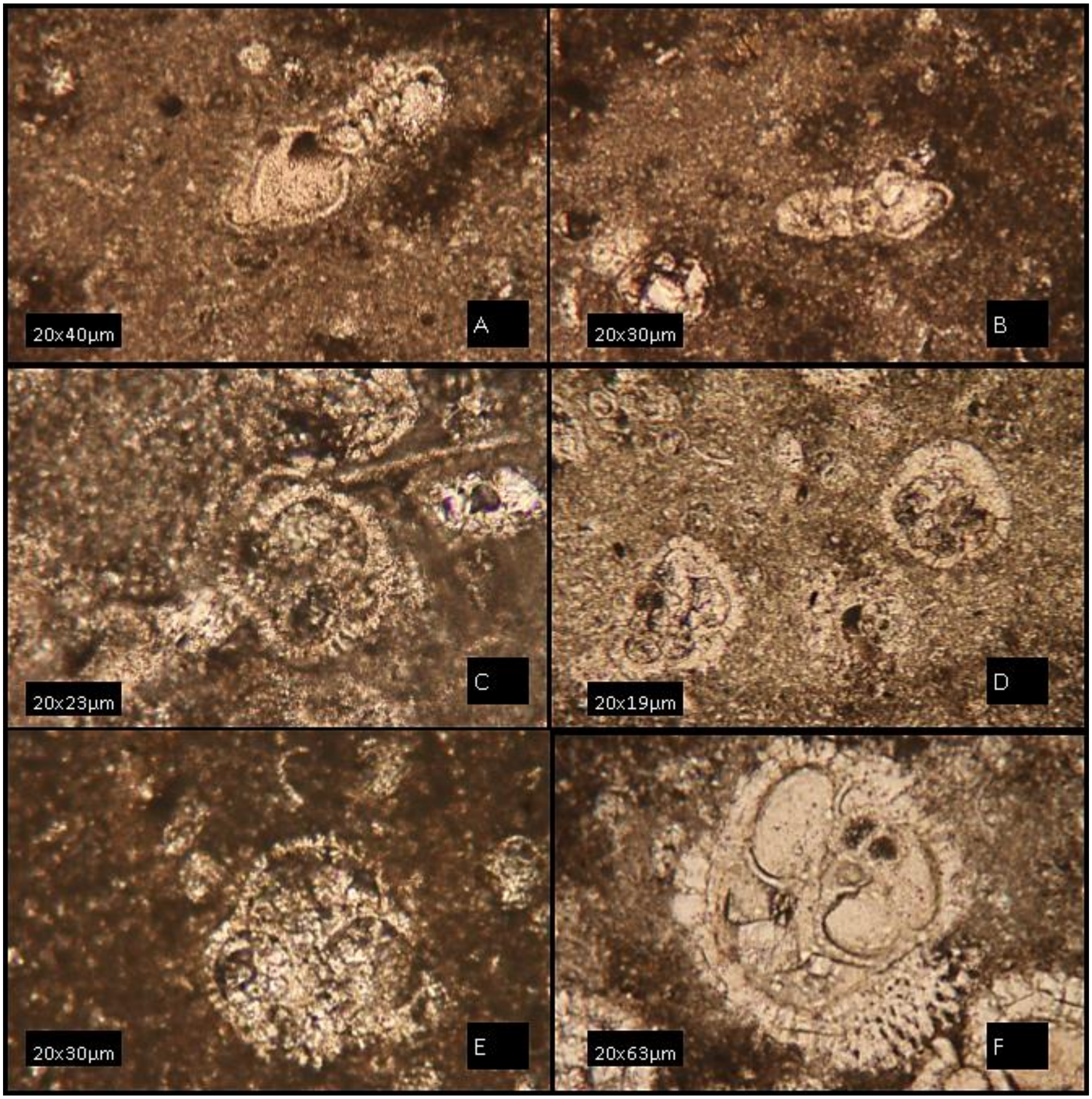


Plate 5:

Astrorotalia palmerae (Slides A & B), ***Globigerinatheka kugleri*** (Slide C), ***Globigerinatheka Mexicana*** (Slide D), ***Globigerinatheka subconglobata*** (Slides E & F)

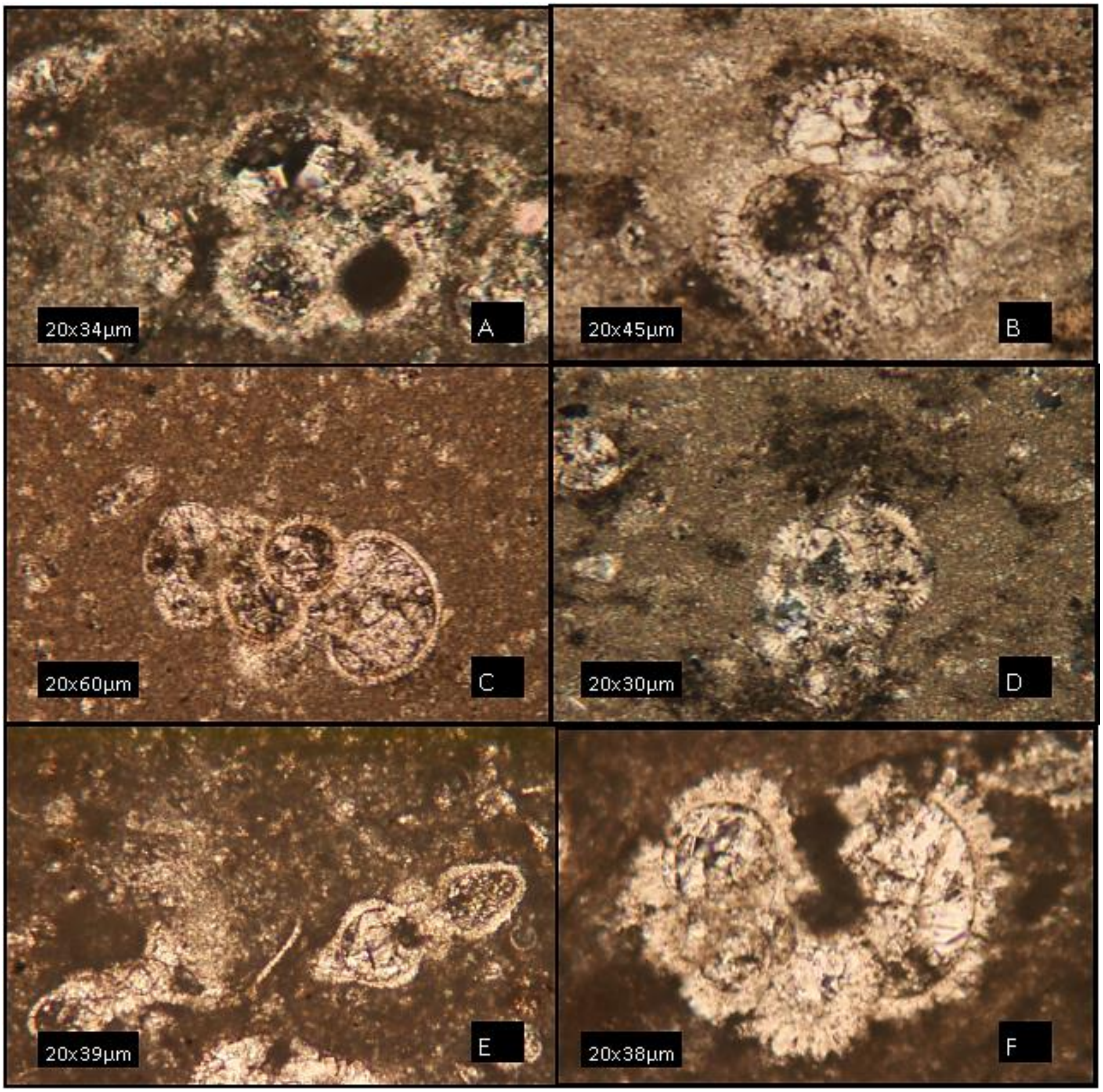


Plate 6:

Globoturbortotalita bassrivernesis (Slides A & B), ***Guembelitrioides nuttalli*** (Slide C & D),

Hantkenina liebusi (Slide E), ***Ignorina broedermanni*** (Slide F)

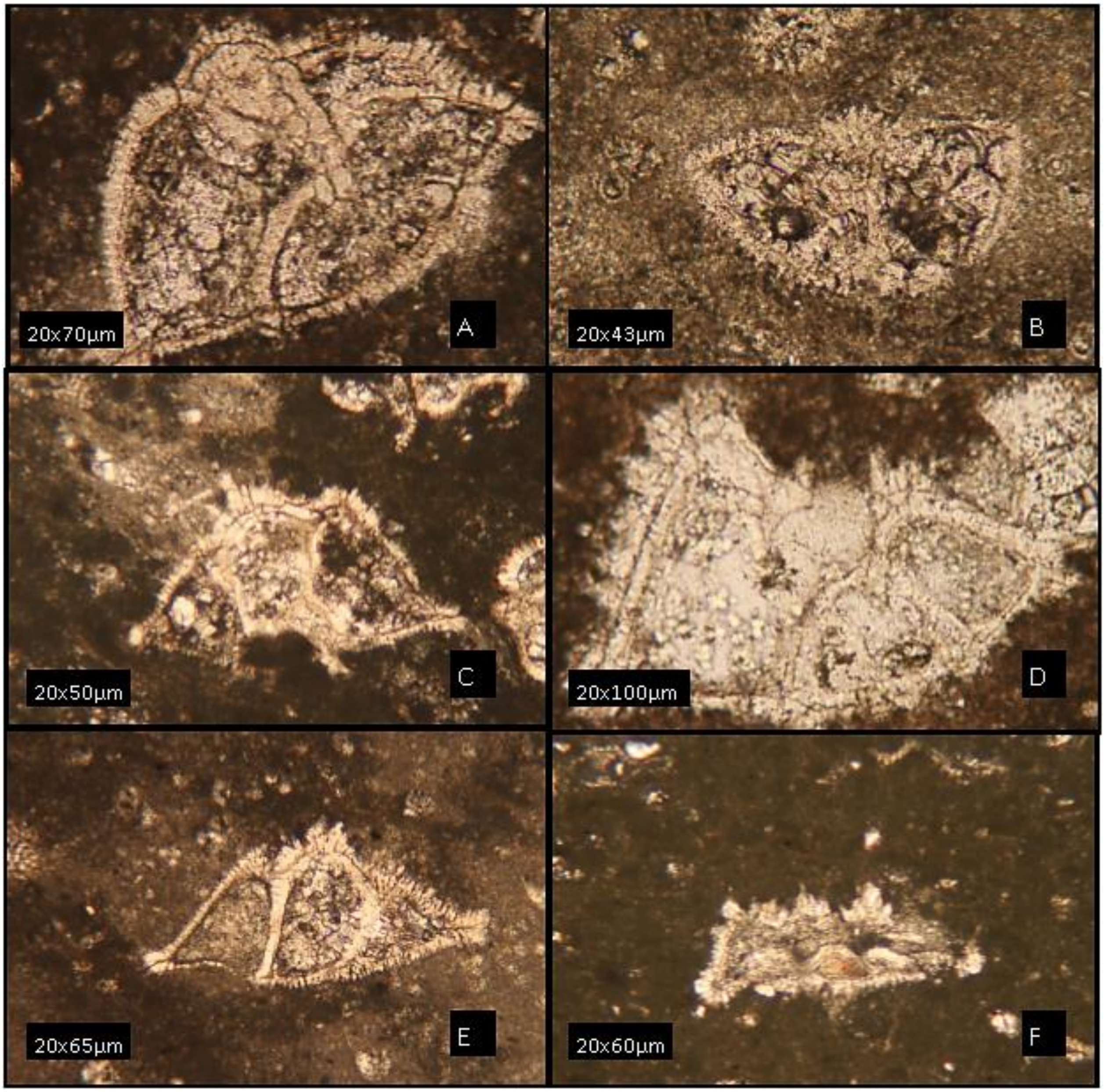


Plate 7:

Morozovella aragonensis (Slides A & B), ***Morozovella caucasica*** (Slides C & D), ***Morozovella crater*** (Slides E & F)

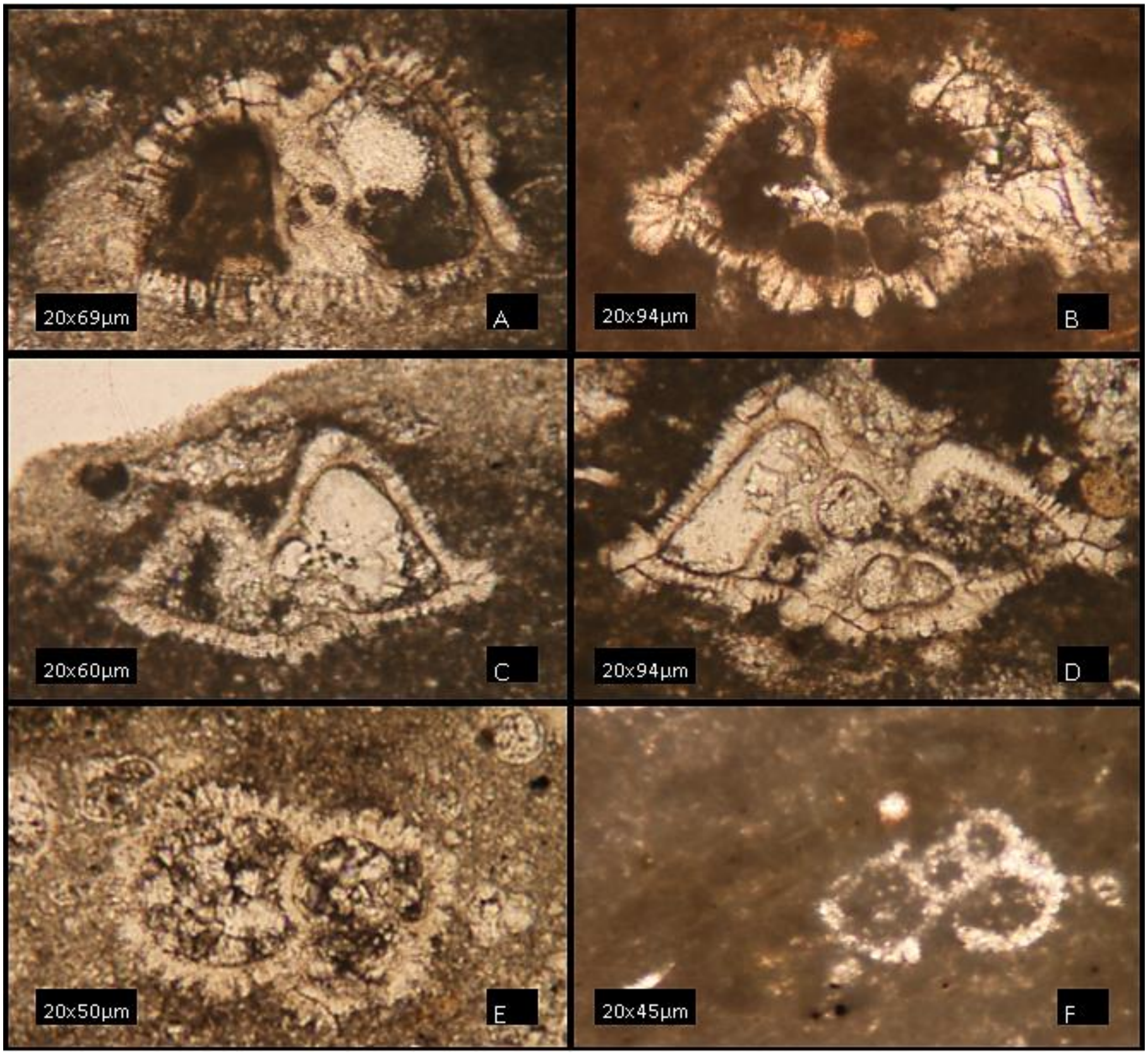


Plate 8:

Morozovella formosa (Slides A & B), ***Morozovella subbotinae*** (Slides C & D), ***Parasubbotina inaequispira*** (Slides E & F)

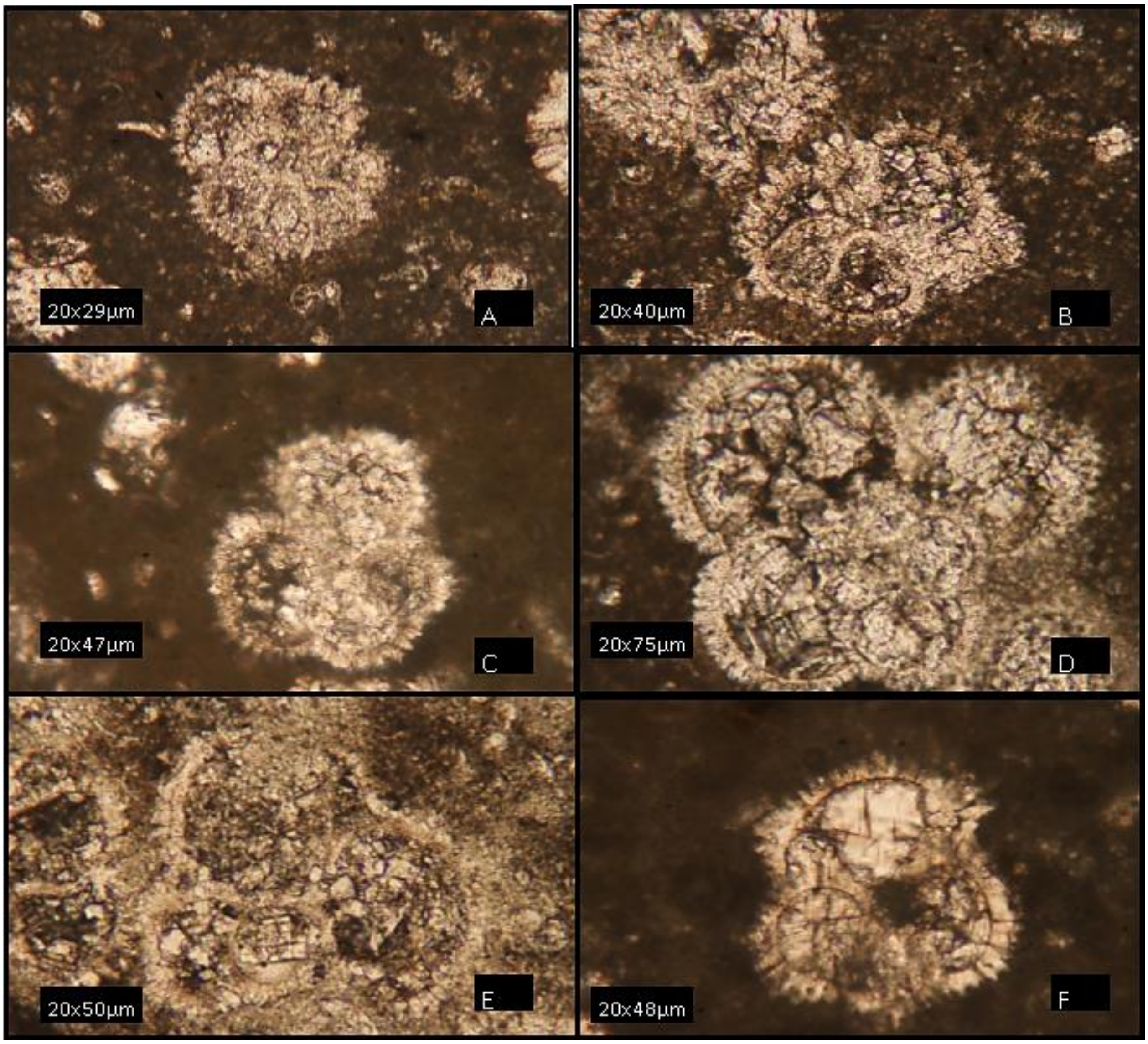


Plate 9:

Problematica lozanoi (Slides A & B), ***Subbotina corpulenta*** (Slides C & D), ***Subbotina crociapertura*** (Slides E & F)

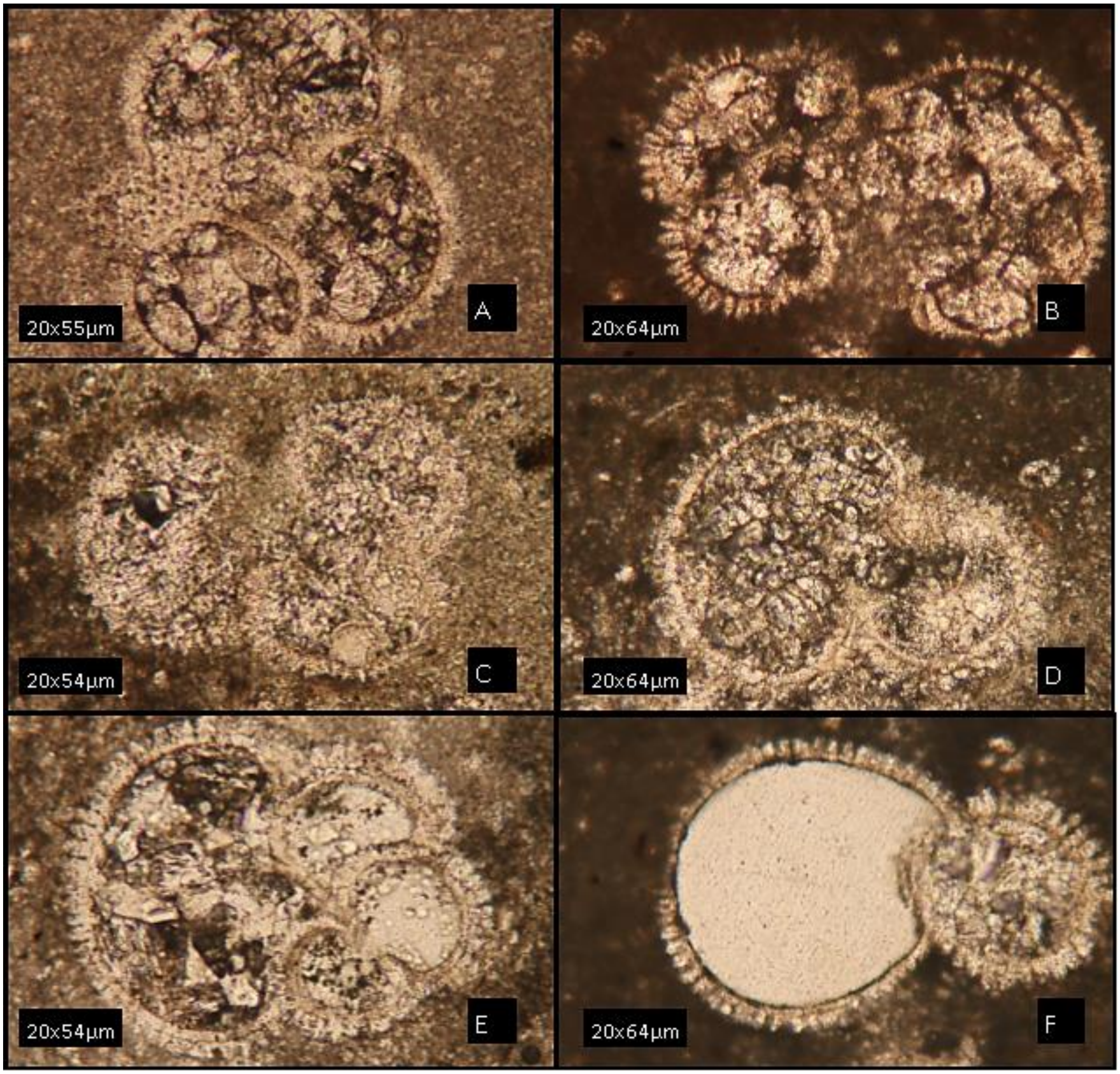


Plate 10:

Subbotina eocaena (Slides A-C) and ***Turborotalia frontosa*** (Slides D-F)

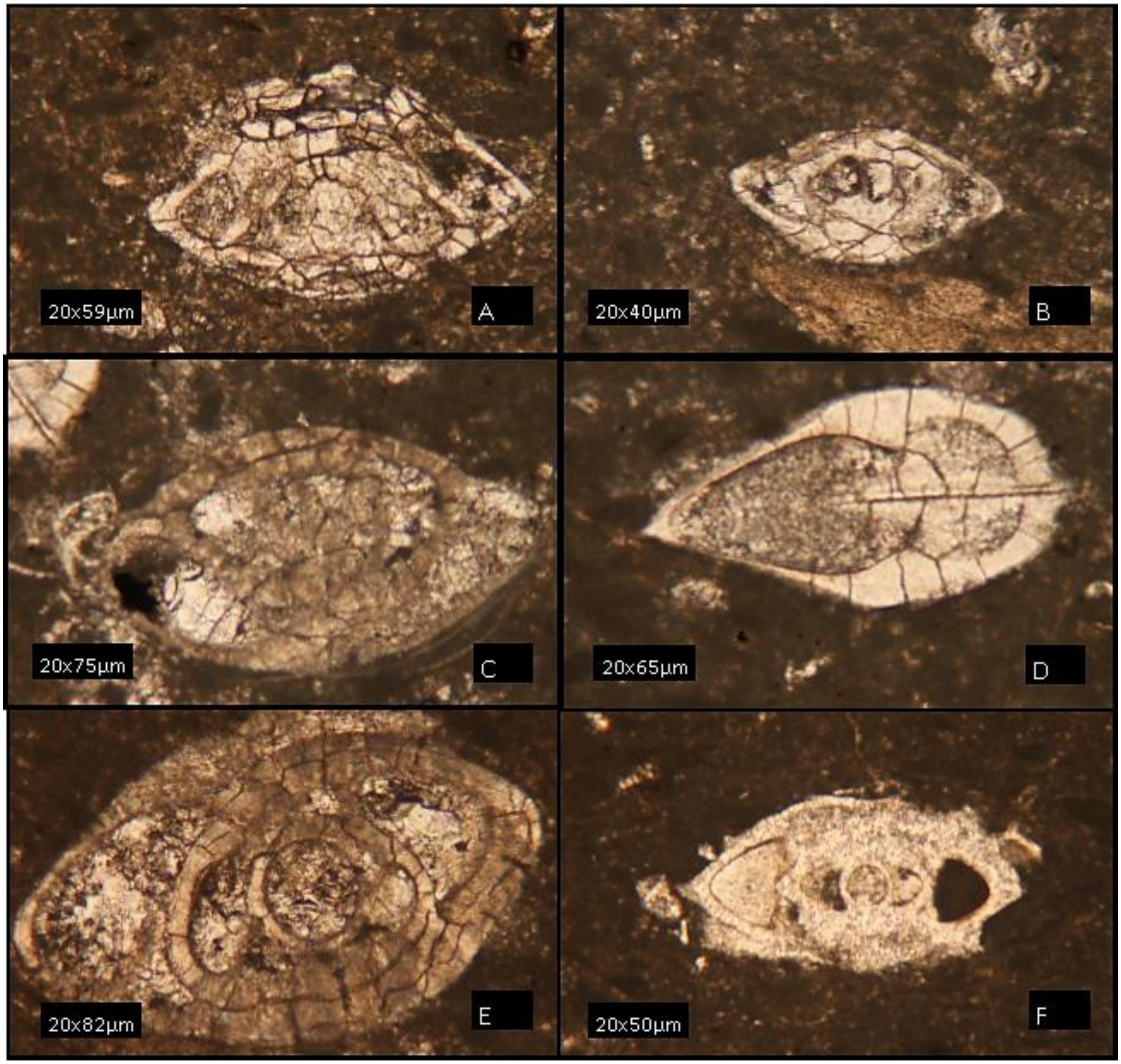


Plate 11:

Benthics

Nummulites sp. (Slides A-D), ***Heterostegina*** (Slide D), ***Discosyclia*** sp. (Slides E-F)